THE INFLUENCE OF THE CAPE FEAR RIVER ON CHARACTERISTICS OF SHELF SEDIMENTS IN LONG BAY, NORTH CAROLINA

Michael P. Slattery

A Thesis Submitted to the
University of North Carolina Wilmington in Partial Fulfillment
Of the Requirements for the Degree of
Master of Science

Department of Geography and Geology

University of North Carolina Wilmington

2006

Approved by

Advisory committee

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Chair

Accepted by

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Dean, Graduate School

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ABSTRACT

The Cape Fear River (CFR) is a low discharge river, which drains the largest area of any rivers fully contained within North Carolina. The river is formed in the Piedmont by the convergence of the Haw and Deep Rivers and then flows southeast through the state terminating into Long Bay in the Atlantic Ocean.

Long Bay is the most southern in a series of bays along the North Carolina coast. Mud drapes observed in the bottom sediment deposits of Long Bay are found proximal to the river mouth up to 8 km offshore and are unique in that no such deposits are found in Onslow Bay to the north. The CFR is the most likely source of this material, though no relationship has been shown between discharge from the river and variations in sediment composition and texture. The nature of these muds (permanent or mobile) is important as mud particles can provide a substrate by which pollutants can be transported into the coastal ocean. If these deposits, then, are stable they could serve as a sink for these pollutants, while if they are mobile they may act to continually reintroduce these materials into the water column. Bi-monthly sampling of both TSS concentrations in the water column and surficial bottom sediment deposits at seven sites (site 1, site 2, site 5, site 6, site 7, site 8 and site 9), starting in the mouth of the river and moving southwest away from the river mouth, occurred from September 2003 through November 2004. Physical parameters such as discharge, precipitation and wind were obtained from outside data sets collected by NOAA, the USGS, the Coastal Ocean Research and Monitoring Program, and the State Climate Office of North Carolina.

Results show that when compared to the river control site (site 1) located directly in the mouth of the river, mean TSS concentrations at those two sites located closest to the CFR mouth (sites 2 and 6) were significantly correlated. The organic content of bottom sediments at sites 2

and 6 was significantly and positively correlated to mud content of bottom sediments. In addition, bottom sediment mud and organic content were significantly and positively correlated to three TSS concentration parameters. It would appear then that at least for those sites proximal to the river mouth a definitive relationship between the TSS concentrations and bottom sediment deposits becomes more clear.

Those sites more distal from the mouth showed little if any variation in both TSS concentrations and sediment composition except in rare occasions specifically following peak discharge events related to an extratropical storms. The infrequency of the sampling made characterization of these more distal four sites (site 5, site 7, site 8, and site 9) difficult, though with an increased sampling frequency it may become possible to define the nature of variability seen at these locations. Site 7 especially would be expected to be impacted by river derived materials.

ACKNOWLEDGEMENTS

First, I must extend a warm thanks to those professors at my undergraduate institution that helped me excel in my early academic endeavors: Dr. Eric Wright, Dr. M. Scott Harris, Dr. Jane Guentzel, Dr. John Steen and Dr. Craig Gilman. Without the tools they provided me I may have never realized the merits of higher academia.

The high spirits of CORMP researchers and crew of the R/V Cape Fear made the long days at sea more pleasure cruise than manual work for which I'm ever indebted to them. Jay Souza and Dave Wells particularly kept the project running like a well-oiled machine while keeping the mood light.

In the lab there was always good company and good talk mixed with hard-nosed science to keep me sane over the long hours of sample analysis. During some cruises Jeff Marshall and Amanda Kahn were key in collecting samples. Around the greater CMS there were always plenty of fellow researchers, like Dr. Gregg Snedden and Wendy Woods, willing to give their expertise to assist in using analytical programs.

The funding by the Department of Earth Sciences, NOAA, and GK-12 allowed me to move ever forward in my degree without worry of financial instability.

I'd like to thank my committee, Dr. Lynn Leonard, Dr. Doug Gamble and Dr. Nancy Grindlay for their unwavering support and patience.

Last, I'd like to thank my wife, Heather Young, for being there and always taking time to be the first to look over my work.

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INTRODUCTION

The Cape Fear River (CFR) is a relatively low discharge river system (annual mean daily discharge of 4,847 $ft^3\,sec^{-1}$ at Lock and Dam #1) located in the east-central portion of North Carolina that flows through the state's most industrialized river basin. The CFR flows southeast, forming an estuary (tidal influence has been measured as much as one hundred six miles up stream) and terminating into Long Bay in the coastal Atlantic Ocean (Patrick, 1996; Mallin, 2004). The CFR originates from the convergence of the Haw and Deep Rivers whose headwaters lie in the Piedmont physiographic province of North Carolina (Figure 1). The area of the Piedmont through which the CFR flows is underlain by Precambrian sedimentary rock and metamorphic deposits or granitic intrusions. The high turbidity seen in the upper part of the CFR mainstem is believed to be due to sediment originating in the Piedmont. In the coastal plain, underlain by Cretaceous sedimentary rocks, the turbidity can mainly be attributed to high dissolved organic content in the water column. The resultant river drains the largest area (24,018 km^2) of any river system contained solely within North Carolina (Patrick, 1996).

Like many of the other rivers located in the southeast United States (SEUS), the CFR receives a large amount of dissolved organic matter (DOM) from upstream freshwater swamps and black water tributaries (Shank et al., 2004b). These areas, high in DOM, contribute 35% of the total area in the CFR drainage basin. The high content of humic substances from blackwater streams and particulate inputs from the Cape Fear mainstem result in the effluent from the CFR to appear as a dark plume that generally propagates south-southwest from the river mouth into Long Bay (Figure 2) (Shank et al., 2004b).

Mud deposits are frequently observed within surficial sediment deposits on continental shelves, particularly, adjacent to mouths of rivers capable of transporting sediment loads much

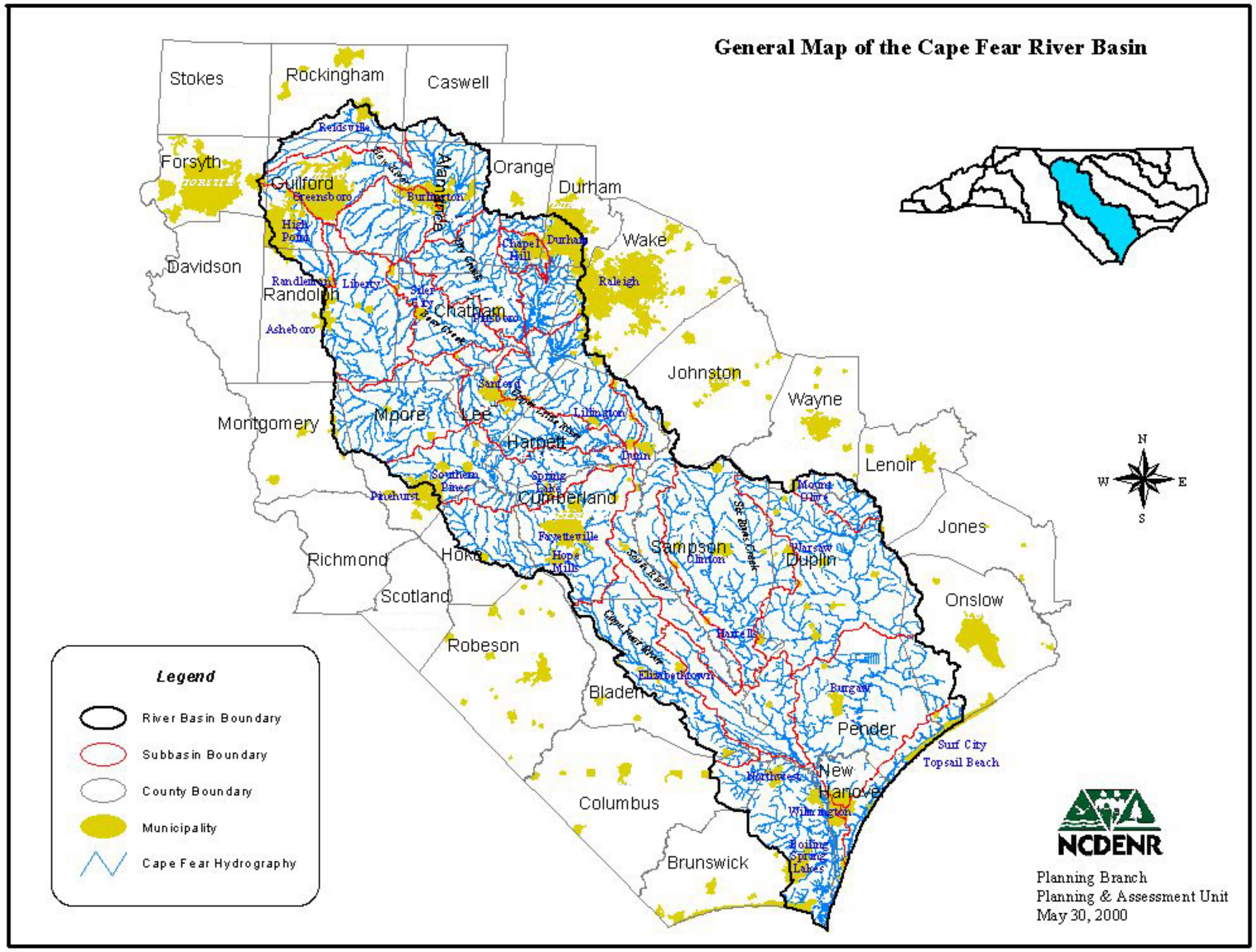
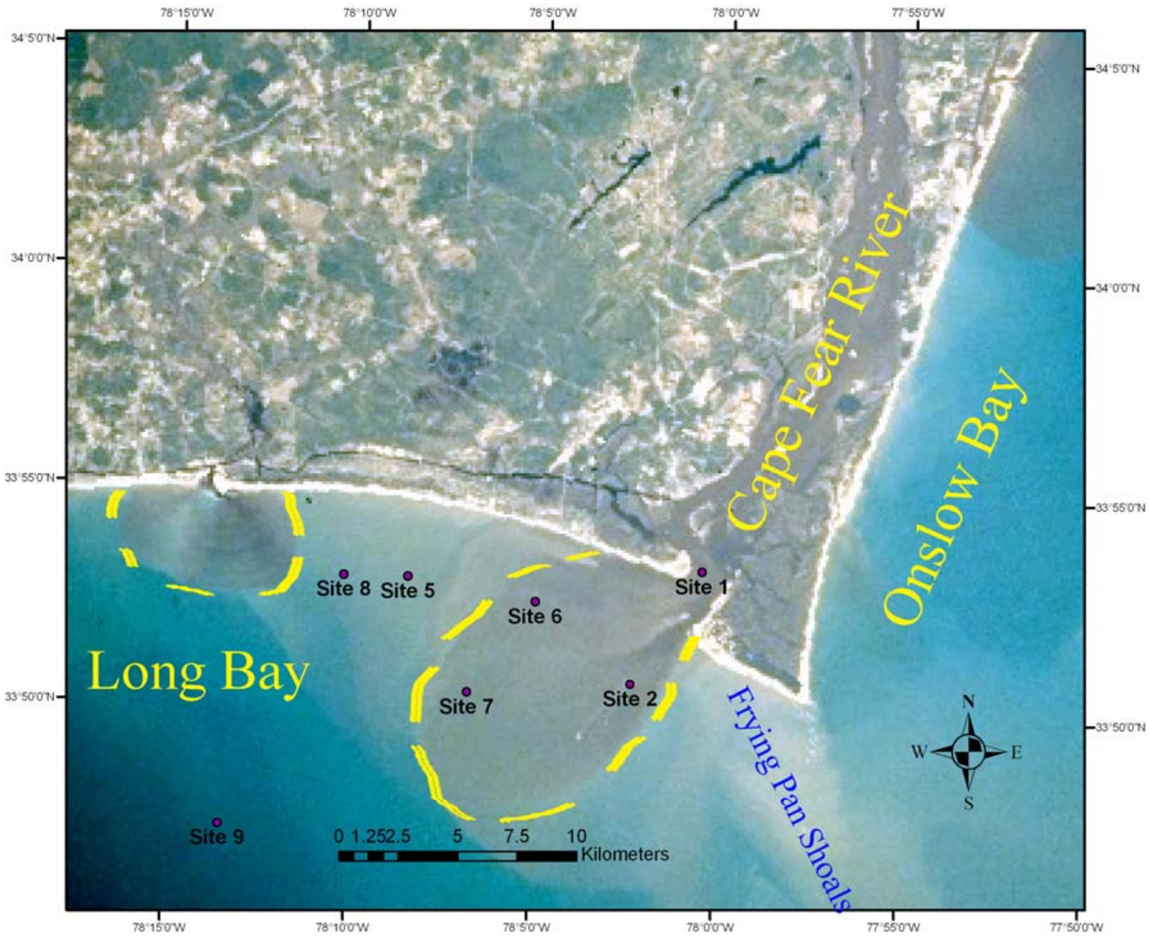


Figure 1. Cape Fear River drainage basin in NC (adopted from http://h2o.enr.state.nc.us/basinwide/whichbasincapefear.htm).

higher than that of the CFR. These mud deposits, however, are generally observed on the mid-shelf as a result of resuspension and transport from the area of initial deposition on the inner shelf (Ogston et al., 2000). In the vicinity of the CFR plume (Figure 2), discontinuous muddy sand deposits and mud drapes have been observed in bottom grab samples collected on the inner shelf (McCleod et al., 2000). While the source of these muds has not yet been ascertained, there are at least two, seemingly obvious, sources: direct input from the CFR, or reworking of underlying relict sediments uncovered due the influence of bottom stresses. In an evaluation of offshore sand deposits for beach renourishment purposes, McCleod et al. (2000) suggest that the relatively high mud content of the shoreface sediments is indicative of significant reworking of these thin (10-300 cm) veneers. Some small areas of less muddy sands are also present and underlying muddy material could be periodically uncovered and provide an additional reworked source of muds in the study area; the exposure is more likely if the sand is subject to sufficient bottom stresses for an extended period of time (Cleary, 1996).

The fate of river derived muds is important to coastal ecosystems as these muds are able to attract ions present in the water column, including pollutants, such as metal cations and nutrients (Mallin et al., 1999). When this attraction occurs, a substrate is provided to the pollutants that enhances their transport potential (Rao, 1993). The CFR has been shown to be a major source of nutrient loading to the coastal ocean and increased levels of phosphorus have been associated with increased turbidity in the plume. These nutrient pulses have also been significantly correlated with increased rainfall and river discharge, thus, it is likely that increased turbidity on the inner shelf is coincident with period of peak discharge or precipitation (Mallin, 2004). Strong correlations between high rainfall, increased discharge, and elevated total suspended sediments have been documented in European rivers (e.g. Lenzi and Marchi, 2000)



Site	Latitude (North)	Longitude (West)	Distance from Site 1(Km)
Site 1	33°53.28'	78°00.47'	0.00
Site 2	33°50.68'	78°02.35'	5.56
Site 5	33°53.00'	78°08.50'	12.40
Site 6	33°52.50'	78°05.00'	7.09
Site 7	33°50.40'	78°06.80'	11.08
Site 8	33°53.00'	78°10.25'	15.10
Site 9	33°47.25'	78°13.50'	22.94

Figure 2. Image of the CFR and plume in Long Bay as seen from space shuttle mission STS062 3/4/1994-3/18/1994. Sampling sites, Lockwood's Folly plume and CFR plume are indicated by dashed yellow lines.(modified from www.redtailcanyon.com/items/155.aspx)

and other southeastern U.S. river systems during El Niño events (Sun and Furbish, 1997; Savidge and Cahoon, 2002). Additionally, sedimentological materials delivered to the coastal oceans during these peak flow events have been shown to comprise a significant portion of inner shelf sediments (Sun and Furbish, 1997; Lenzi and Marchi, 2000).

It is not uncommon to find estuarine derived sedimentary material on the continental shelf. In a study of terrestrial sediment discharge and distribution on the Bay of Biscay shelf, which is located in the Atlantic Ocean west of France and north of Spain, Castaing et al. (1999) used seasonal total suspended solids (TSS) fluctuations and the distribution of the shelf sediment deposits to positively identify an estuarine source of the sediment. Further, their results indicated that the sediments initially deposited on the shelf were likely to be re-mobilized when subject to various physical processes such as wave action, tidal currents, and along- and across –shelf wind driven currents (Wright and Nittrouer, 1995; Ogston et al., 2000). Limited ADCP data collected by McNinch in the vicinity of the CFR mouth at (http://www.frf.usace.army.mil/capefear/sediments.shtml) indicate the presence of well-defined tidal current patterns ((33°52.90'N, 78°00.10'W). Further, wave action and along- and across-shelf storm-generated wind-driven currents have been identified as important sediment transport mechanisms in Onslow Bay, located north (Figure 2) of the study area (Wren and Leonard, 2005). Given the influence of tidal currents and potential for storm impacts in the study area, it is unlikely that the deposition of these muds provides a stable sink for river-derived pollutants. More likely, the re-mobilization of the observed inner-shelf deposits provides a mechanism by which pollutants are continually reintroduced into the ecosystem.

Although numerous studies have explored the contributions of river-discharged sediment to the nearshore zone and inner shelf (e.g. Amarasekera et al., 1997; Cordova, 1997; Liu, 2000), few have focused on rivers that are considered relatively low discharge or non-delta forming. Many such rivers exist in the Southeastern United States (SEUS), however, little information is available that describe sediment delivery to this large and ecologically rich portion of the United States coast. Recently, Kim and Voulgaris (2004) used Optical Backscatterence Sensor (OBS) and Laser In-Situ Scattering-Transmissometer (LISST) techniques to characterize the particle size traits of materials in suspension within the CFR plume. This work, which was undertaken during the same period as the research described in this thesis, observed that Suspended Sediment Concentrations (SSC) were generally higher at the base of the water column at stations closer to the river mouth and that concentrations decreased at those sites further from the river mouth. In general, the grain size of suspended particles decreased during low discharge periods and increased with distance from the river mouth. Larger particles also were present at the pycnocline at some of the sites and attributed to flocculation of particles during the mixing of salt water and freshwater. Because many of the Kim and Voulgaris (2004) sampling events were coincident with sampling efforts undertaken for the present study, their findings are directly applicable to the results that will be presented in this document.

The hypothesis of this study is that the presence and distribution of muds in Long Bay is positively and significantly correlated with increased TSS concentrations in the overlying water column following periods of peak river discharge. The main objective of this study is to determine if TSS transported to the coastal ocean by the CFR exert a detectable effect on the texture of sediment deposits collected in Long Bay.

Additional objectives of this study are (Figure 3):

1. To determine spatial variations in inner-shelf sediment texture and organic content and TSS concentration, and to determine if variability among these parameters is a function of proximity to the CFR mouth.
2. To determine temporal variations in inner-shelf sediment texture and organic content and in TSS concentrations, and to relate these to river discharge and prevailing wind conditions.
3. To determine if changes in sediment texture or percent organic content are correlated with TSS concentration in the overlying water column and/or with elevated discharge from the CFR.

Study Area

The study area is located off the southeastern coast of North Carolina in Long Bay, which is the Southern most of the series of bays making up North Carolina's shoreline (Figure 2). Long Bay is separated from Onslow Bay by Frying Pan Shoals (Figure 2). Frying Pan Shoals comprise a significant sandy deposit that extends roughly 25 km south-southeast from the mouth of the CFR mouth (Thompson and McKee, 2002) and could provide a local source of sands to the plume region during strong wave events. This area of the eastern seaboard is wave dominated, though wind driven currents do play a part in the dynamics of the physical regime, and experiences semi-diurnal tides with a range of approximately 1.5 m (Shank et al., 2004a).

Sampling of the water column and bottom sediments began in September 2003 and was repeated bimonthly through November 2004 at seven sampling sites (1, 2, and 5-9) (Figure 2) in Long Bay. The seven sites were chosen to encompass a range of potential river inputs based on historical data of optical water properties associated with the optical plume. Site 1, in the mouth

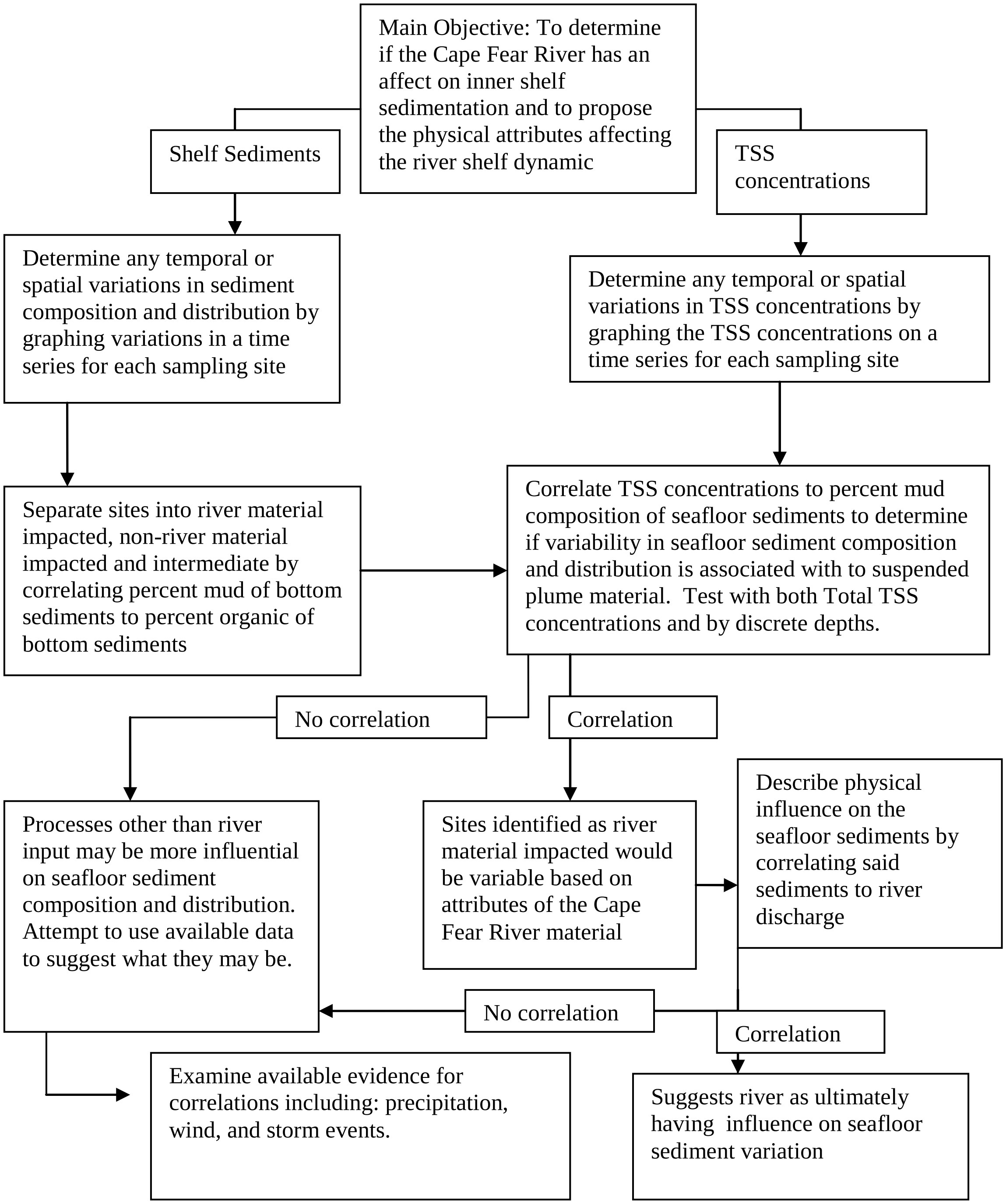


Figure 3. Flowchart of the objectives and strategies for this study.

of the river, is positioned between Bald Head Island to the east and by Oak Island to the west and was chosen as a control site for river derived TSS concentrations. Sites 2 and 6 were chosen as those sites believed to be impacted regularly by river material; while sites 5 and 7 were presumed to be impacted by the river material only periodically. Sites 8 and 9 are two positions thought to be rarely impacted by the river material and were therefore treated as non-river sites.

MATERIALS AND METHODS

Shipboard Methods

Bimonthly sampling cruises were conducted aboard the *R/V Cape Fear*. At each of the seven stations, seafloor sediments were collected using a ponar grab and then stored in Ziploc© bags. Also at each station, water column samples were collected at three depths (top, middle and bottom) utilizing a Niskin rosette. Following on-deck retrieval, the Niskin bottles were inverted several times to homogenize the sample and three 600 mL aliquots of water were drawn for subsampling. Approximately 500 mL of each aliquot were filtered during the cruise through a pre-weighed, pre-combusted 1 μm glass fiber filter (PALL Life Sciences P/N 61631) to determine TSS concentrations. In instances of high turbidity, it was necessary to use smaller volumes to avoid clogging the filters. Sediments and filters were then returned to the laboratory for further analysis, which is described below.

Laboratory Methods

The grain size of the bottom sediments was established by first wet-sieving 150 mL of the sediment sample through a 63 μm sieve to separate the fine fraction (diameter<63 μm) from the sand fraction (diameter>63 μm). The fine fraction was then dried and weighed, while the sand fraction was dried and subsequently sieved through a nested sieve with mesh sizes from 2 mm-63 μm at 1 phi intervals (Folk, 1980). The sediment in each sieve was then weighed (in grams). Sediment grain size was reported as a percentage (i.e. percent muds and percent sands) to determine relative abundance of mud. A dollop (from 2-30 grams depending on mud content) of sample from each site was combusted in a 500°C oven for four hours to determine the organic constituent of the sediments.

In the laboratory, the glass filters for TSS measurement were dried in a 40°C drying oven for 24-36 hours and weighed to determine concentration in mg L^{-1}. Organic content of the TSS constituent was determined by combusting the filters at 450°C for two hours, weighing the combusted filters, and determining the weight percentage of material lost as volatiles.

Physical Parameters

Precipitation values were supplied by the State Climate Office of North Carolina for Greensboro Airport, station KGSO (302 km upstream), in Guilford County, NC, as precipitation from this site was previously correlated with discharge at Lock and Dam #1 (59 Km upstream) (r=0.60) by Mallin et al. (1999). Precipitation recorded at Lock and Dam #1 in the coastal plain was gathered from the USGS station 02105769 due to the rain gauge's proximity to the mouth of the CFR, compared to that of KGSO. Meteorological data from the study area was obtained from NOAA's Frying Pan Tower (Station FPSN7, 58.7 km from mouth) August 1, 2003-February 25, 2004 and after deployment of a new oceanographic buoy from NOAA's Frying Pan Buoy (Station 41013, 55.6 km from mouth) February 26, 2004-November 30, 2004. Both stations were located southeast of the river mouth on Frying Pan Shoals. Daily discharge at the mouth of the CFR was obtained via the Coastal Ocean Research and Monitoring Program (CORMP) website (http://www.cormp.org/stream.php), which calculated the discharge using methods described in Carpenter (1979).

Peak discharge events were defined as those periods during which discharge exceeded one standard deviation above the thirty-year (1972-2002) discharge average, similar in methodology to Camilloni and Barros (2003) (Figure 4). In instances where two peak discharge peak events were monitored, the event with the higher maximum discharge was used.

Analytical Tools

All correlation analyses were completed with the Microsoft Excel Data Analysis Toolbox using a significance level of $p<0.05$. Functions (f_vecuv, f_vecplot, and f_shadebox) available via the Fathom Toolbox (http://www.rsmas.miami.edu/personal/djones/) for Matlab version 7.0.4.352 (R14SP2) were used to plot wind vector data, discharge, and precipitation and denote sampling times (Figures 5, 6, 7A-B respectively). The fixgaps command, in Matlab, was used to interpolate gaps in the data for graphical purposes, but interpolated values were not used in statistical tests. The wind data were then used as a proxy in an attempt to determine the direction in which the plume propagates (more towards site 6 or towards site 2).

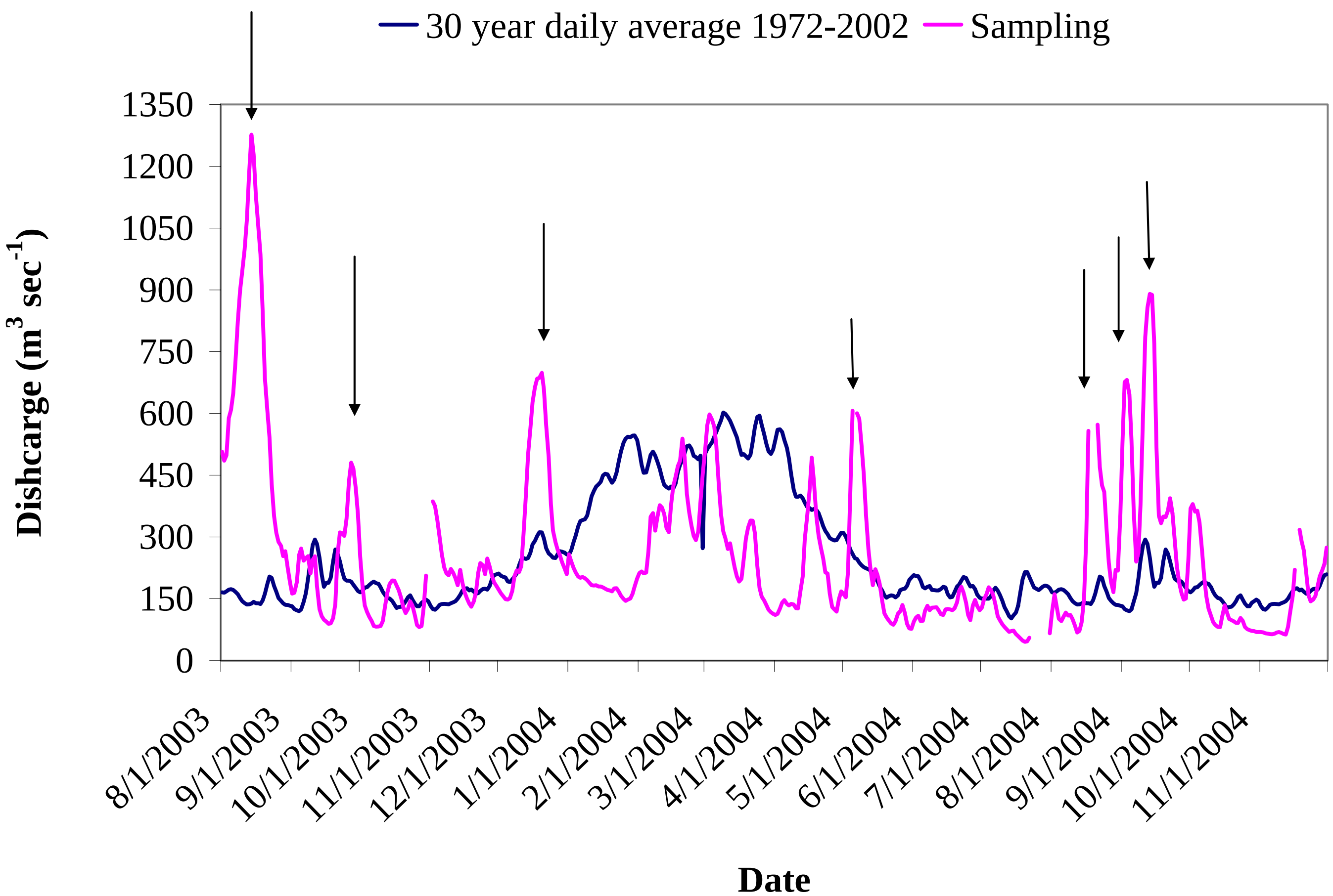


Figure 4. Discharge during the study time and thirty year mean daily discharge (1972-2002) at the CFR mouth (Discharge events that were greater than one standard deviation above the thirty year mean are denoted with arrows).

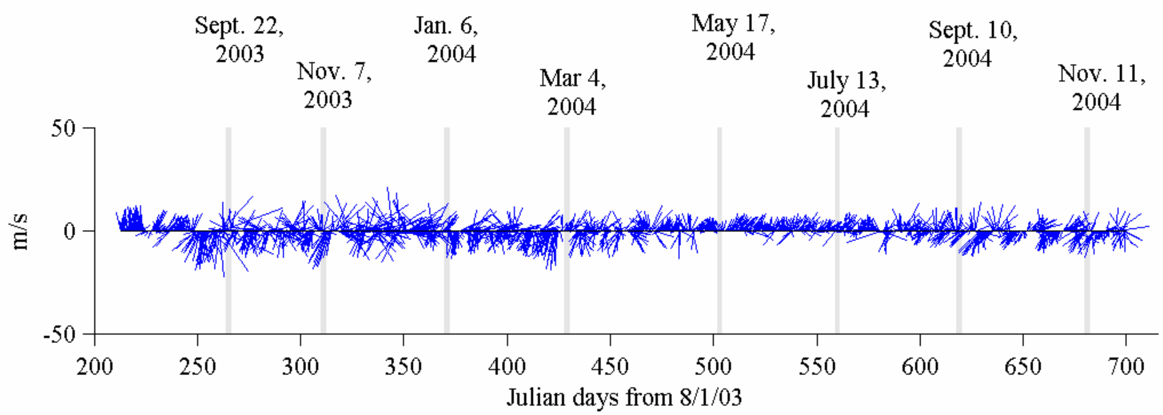


Figure 5. Time series display of wind speed and direction at Frying Pan buoy and tower over the study period. The direction of the blue vectors indicate direction from which the wind is blowing relative to north, while the length is indicative of magnitude.

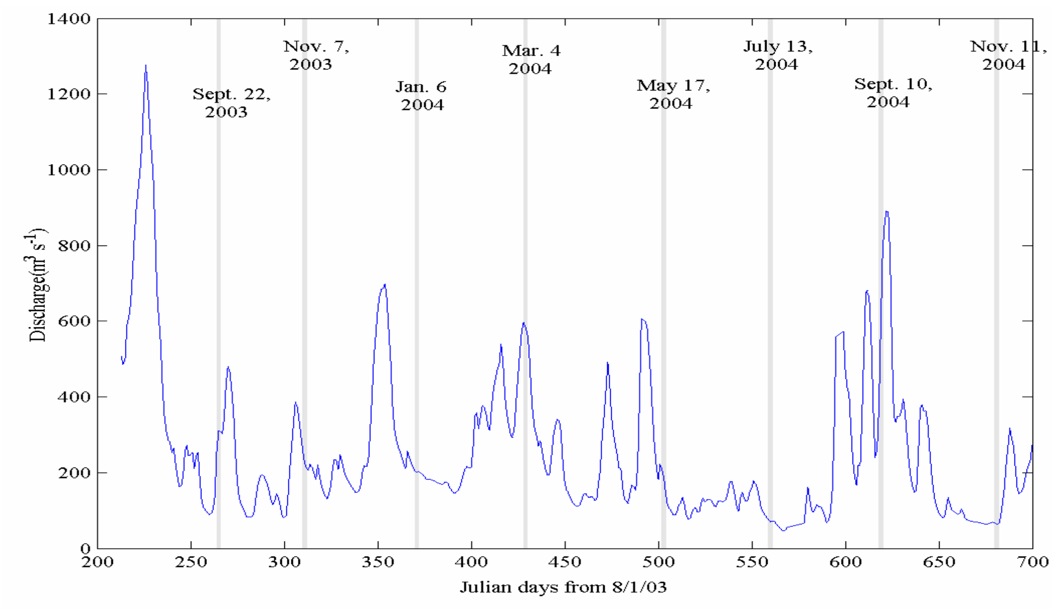


Figure 6. Time series display of discharge at the CFR mouth. Data gaps have been interpolated using Matlab fixgaps command (display purposes only). Sampling times are denoted by date and shaded region.

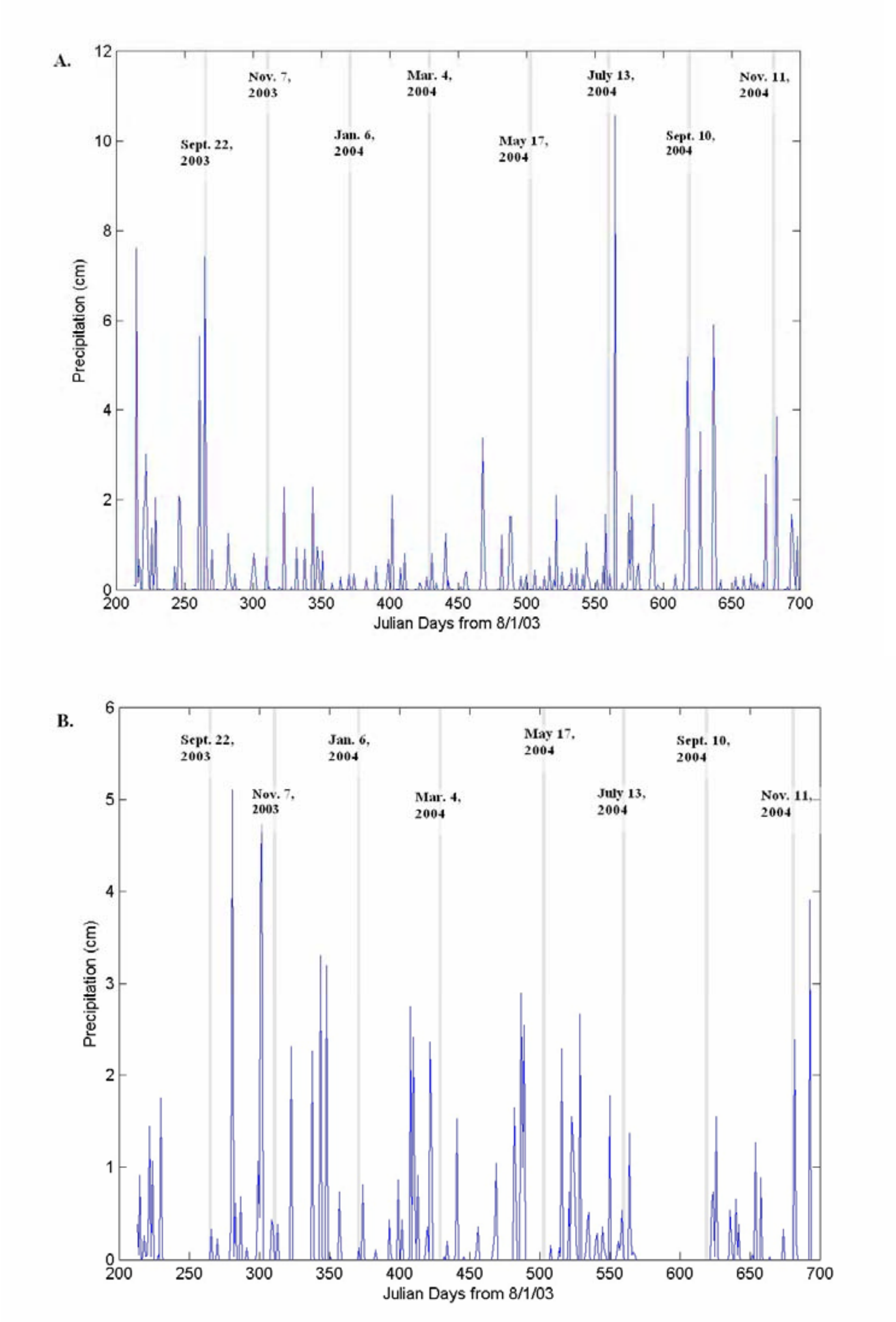


Figure 7. Time series display of precipitation (cm) at both Greensboro Airport and Lock and Dam #1. A.)hourly precipitation at Greensboro Airport B.)hourly precipitation at Lock and Dam #1.

RESULTS

River Discharge, Precipitation, and Wind

The thirty-year average (figure 4) for the CFR indicates that daily discharge is higher in late winter and early spring (February through April) and following tropical and extratropical events (Mallin, 2004). Over the duration of this study several tropical storms and hurricanes affected the area (Figures 8 A-H and 9 A-B). In 2003 only Hurricane Isabel affected North Carolina, making landfall north of the study area. Precipitation, possibly due to Isabel (Figure 8A), was observed on September 18, but discharge appeared to be associated with precipitation after this storm. Storm activity was more intense during 2004 with seven tropical storms or hurricanes including: Alex (Figure 8B), Bonnie (Figure 8C), Charley (Figure 8D), Frances (Figure 8E), Gaston (Figure 8F), Ivan (Figure 8G) and Jeanne (Figure 8H), moving through or near North Carolina. Appreciable precipitation events that appear to be associated with these storms occurred on September 8, 2004 (Frances), September 18, 2004 (Ivan) and September 28, 2004 (Jeanne) (Figure 9A-B). Precipitation data was unavailable from Lock and Dam #1 from July 23, 2004-September 11, 2004, but the graphical discharge event noted on August 17, 2004 (Figure 9) is suggestive of increased rainfall associated with Hurricane Charley which moved through the Coastal Plain on August 14, 2004, and Hurricane Bonnie which passed through the region one day earlier. Similarly the elevated discharge noted on September 3, 2004 (Figure 9) may have been due to the passage of Gaston, which, moved through the Coastal Plain four days earlier.

Discharge during winter and spring were not demonstrative of the thirty-year trend, showing lower than expected daily discharge values. The period from June 2004 through early

August 2004 was characterized by the lowest discharge recorded over the entire study period, consistent with the thirty-year trend.

Some periods of high precipitation were not associated with tropical storms such as September 2004. Other periods of elevated precipitation such as early August 2003, early October 2003, and September-October 2004 were short-lived and intermittent among overall drier periods. The maximum daily precipitation at Lock and Dam #1 was 2 inches though most of the rain events produced between 0.5 and 1 inch. There were several daily precipitation events at Greensboro Airport in excess of 3 inches with a maximum of 4 inches, though the majority were still between 0.5 and 1 inch.

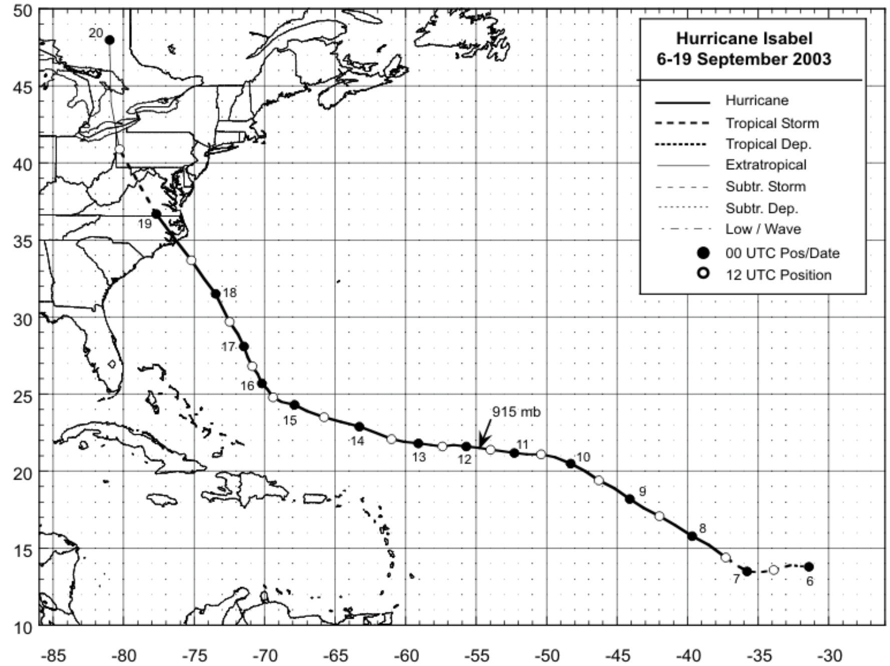
High precipitation preceding discharge events appeared to coincide with rates measured at Greensboro Airport (Figure 9A) as suggested in Mallin et al. (1999), but also with Lock and Dam #1 (Figure 9B). Peak discharge events in August 2003, September 2003, and the two events in September 2004 all were preceded by rainy periods measured at Greensboro Airport which may have allowed for materials derived from piedmont sources to be carried downstream by the river (Figure 9A).

Peak discharge events in December 2003 and May 2004, however, were preceded by precipitation events measured at Lock and Dam #1 thus the most likely source of material introduced to the river would be coastal plain sediments (Figure 9B). The discharge peaks in November 2003, and February and March 2004 were also preceded by rainy events at Lock and Dam #1 while the April 2004, August 2004, and October 2004 graphical peaks were preceded by rain recorded at Greensboro Airport (Figure 9A-B).

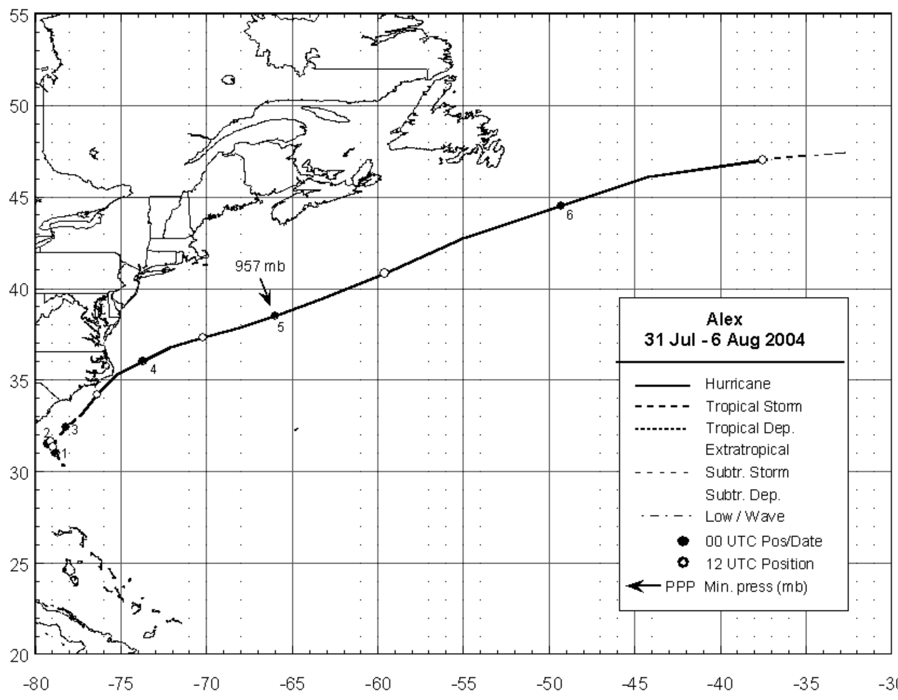
Wind direction was variable over the duration of the study (Figure 5), however, it frequently blew from the south-southwest or north-northeast for extended periods of time.

Figure 8. Tracks of tropical systems affecting the study region including Cape Fear River drainage basin over the period of the study. A.) September 2003 Hurricane Isabel was the lone tropical system affecting the study region, in 2004, B.)Alex, C.)Bonnie, D.)Charley, E.)Frances, F.)Gaston, G.)Ivan and H.)Jeanne all affected North Carolina. (tracks from NOAA.)

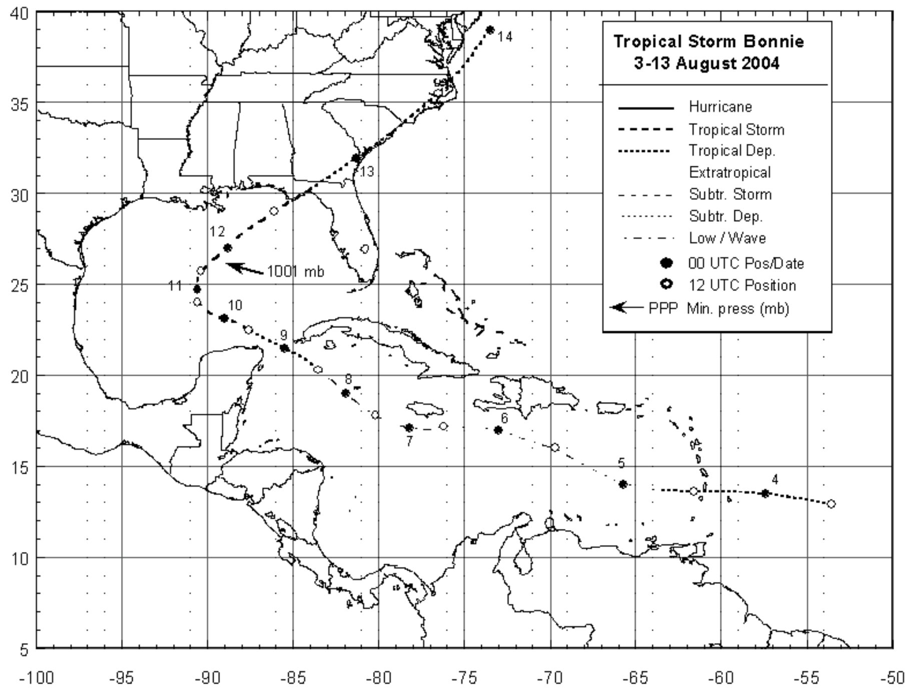
A.


Hurricane Isabel
6-19 September 2003
Hurricane
Tropical Storm
Tropical Dep.
Extratropical
Subtr. Storm
Subtr. Dep.
Low / Wave
00 UTC Pos/Date
12 UTC Position
915 mb

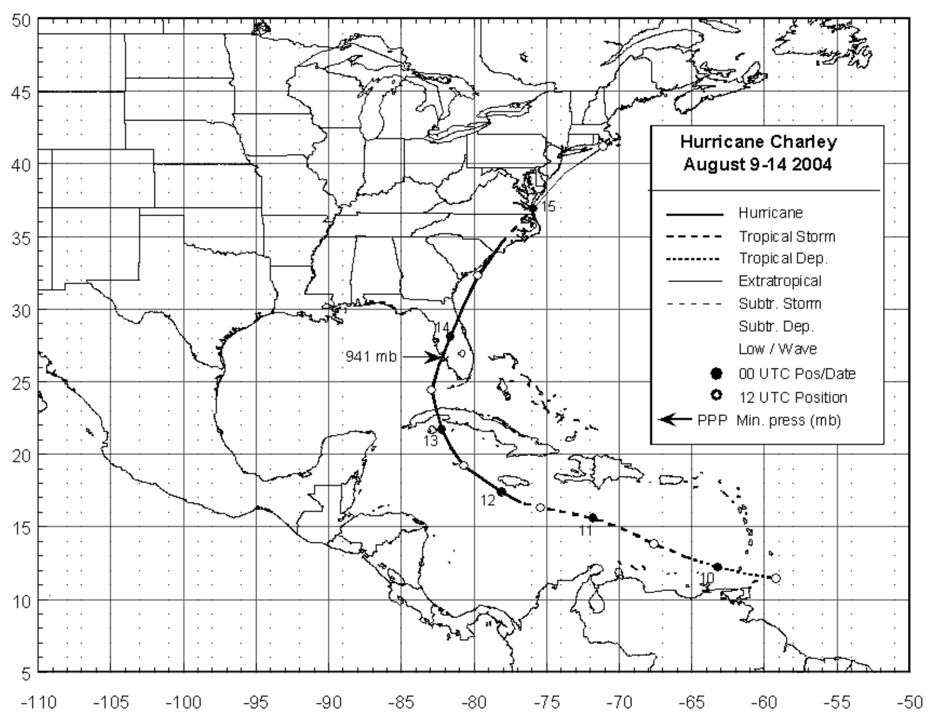
B.


Alex
31 Jul - 6 Aug 2004
Hurricane
Tropical Storm
Tropical Dep.
Extratropical
Subtr. Storm
Subtr. Dep.
Low / Wave
00 UTC Pos/Date
12 UTC Position
PPP Min. press (mb)
957 mb

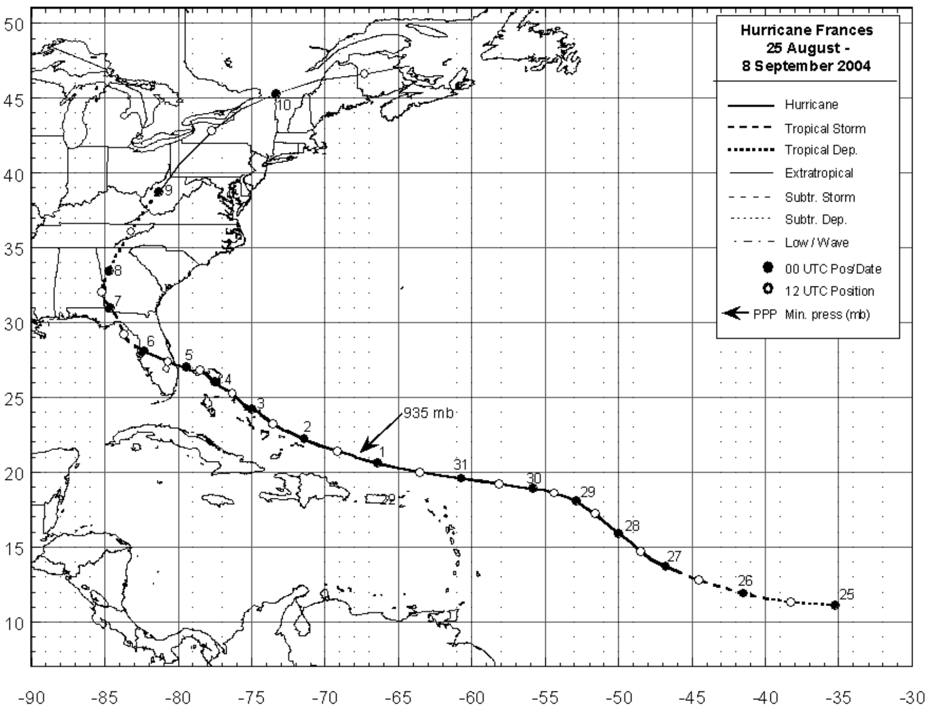
C.


Tropical Storm Bonnie
3-13 August 2004
Hurricane
Tropical Storm
Tropical Dep.
Extratropical
Subtr. Storm
Subtr. Dep.
Low / Wave
00 UTC Pos/Date
12 UTC Position
PPP Min. press (mb)
1001 mb

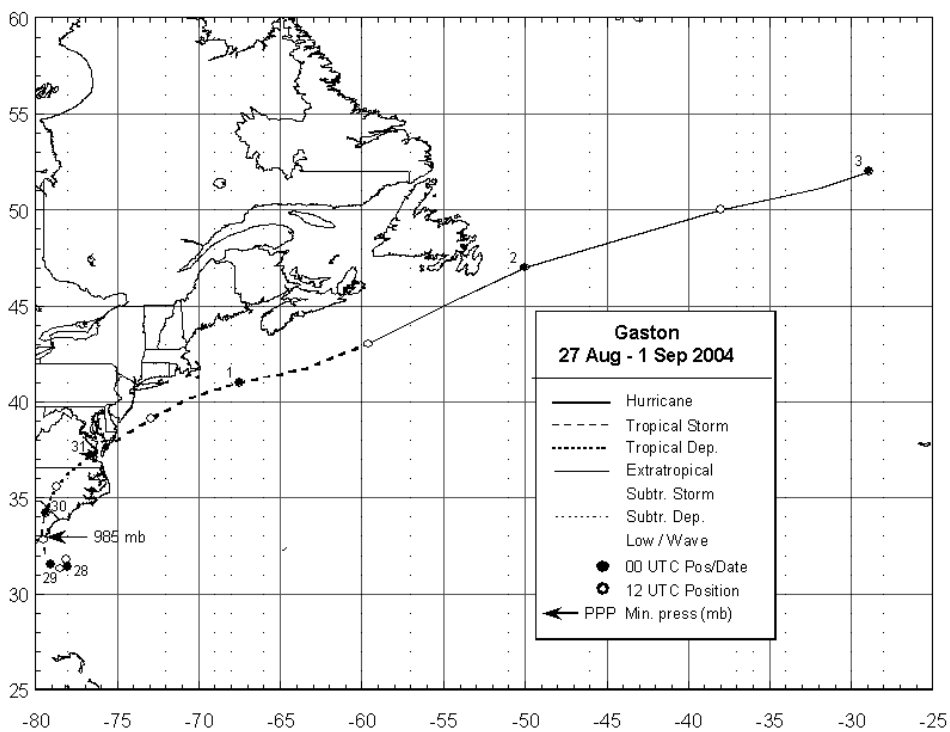
D.


Hurricane Charley
August 9-14 2004
Hurricane
Tropical Storm
Tropical Dep.
Extratropical
Subtr. Storm
Subtr. Dep.
Low / Wave
00 UTC Pos/Date
12 UTC Position
PPP Min. press (mb)
941 mb

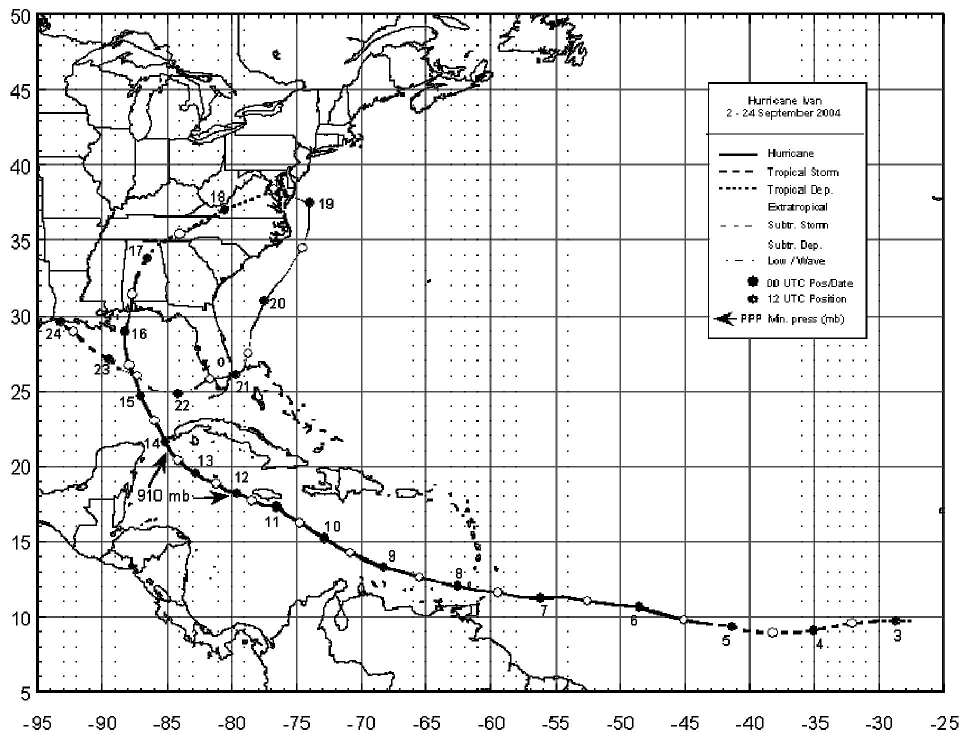
E.


Hurricane Frances
25 August -
8 September 2004
Hurricane
Tropical Storm
Tropical Dep.
Extratropical
Subtr. Storm
Subtr. Dep.
Low / Wave
00 UTC Pos/Date
12 UTC Position
PPP Min. press (mb)
935 mb

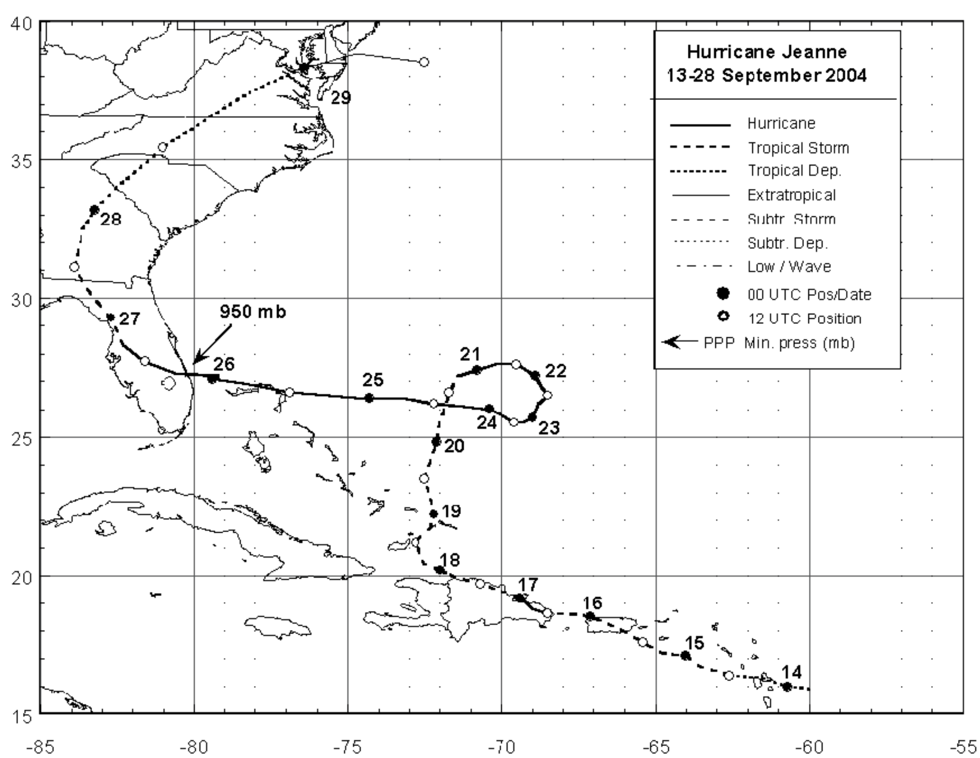
F.

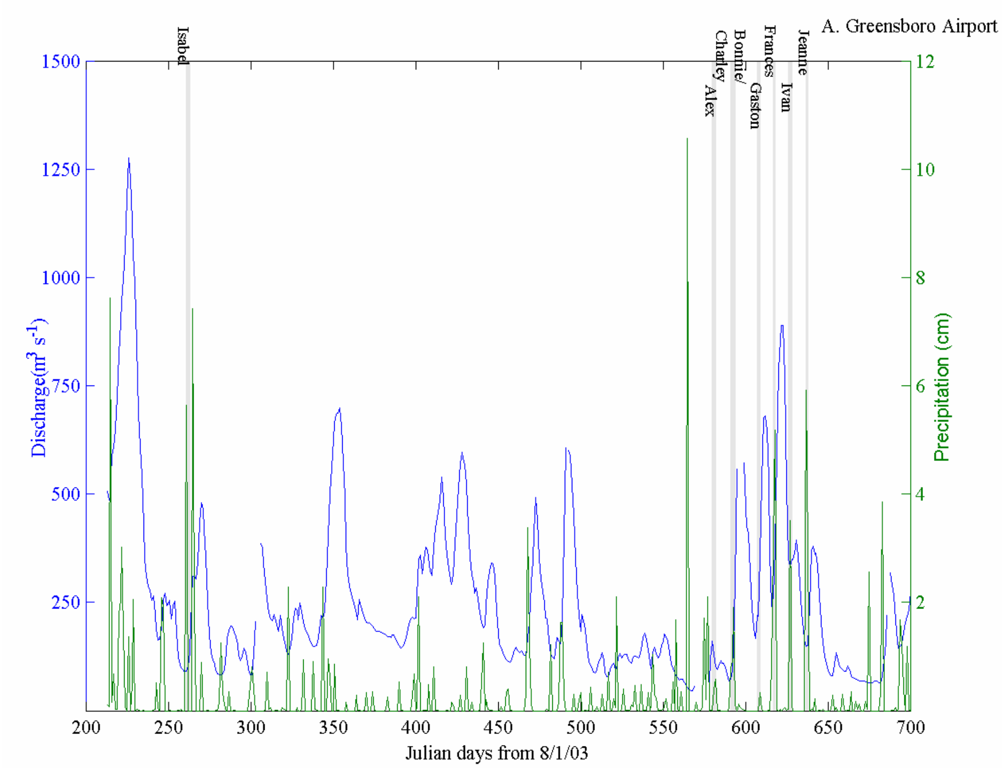

Gaston
27 Aug - 1 Sep 2004
Hurricane
Tropical Storm
Tropical Dep.
Extratropical
Subtr. Storm
Subtr. Dep.
Low / Wave
00 UTC Pos/Date
12 UTC Position
PPP Min. press (mb)
985 mb

G.


Hurricane Ivan
2 - 24 September 2004
Hurricane
Tropical Storm
Tropical Dep.
Extratropical
Subtr. Storm
Subtr. Dep.
Low / Wave
00 UTC Pos/Date
12 UTC Position
PPP Min. press (mb)
910 mb

H.


Hurricane Jeanne
13-28 September 2004
Hurricane
Tropical Storm
Tropical Dep.
Extratropical
Subtr. Storm
Subtr. Dep.
Low / Wave
00 UTC Pos/Date
12 UTC Position
PPP Min. press (mb)
950 mb



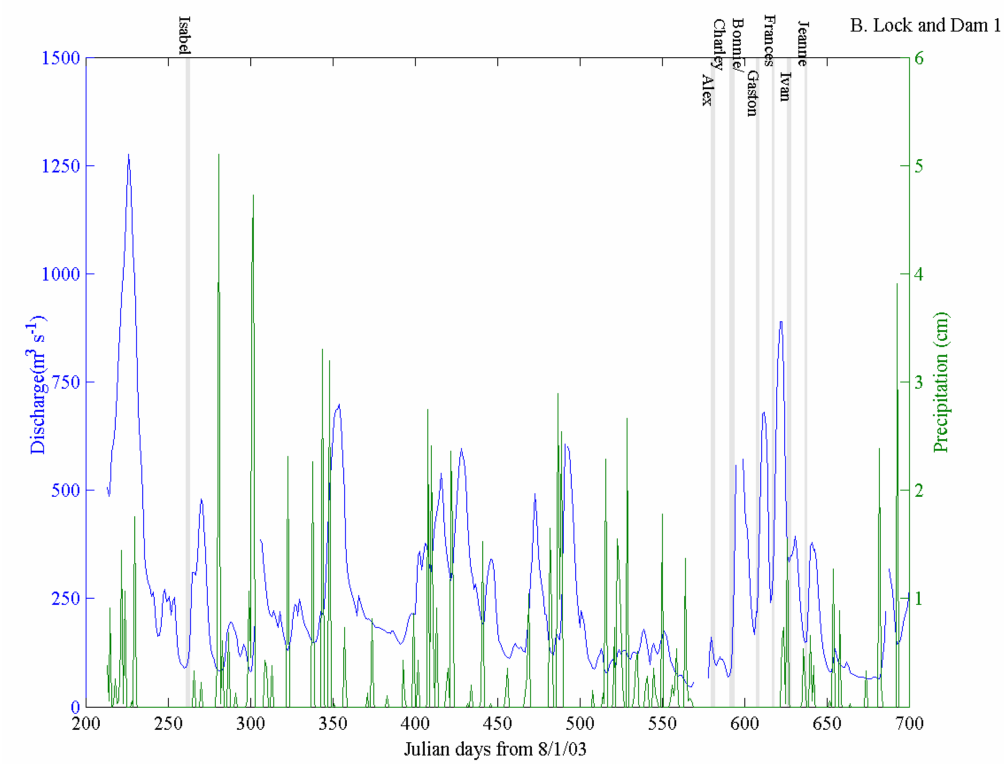


Figure 9. Total daily precipitation and discharge at the mouth of the CFR. A.) Greensboro Airport daily precipitation. B.) Lock and Dam #1 daily precipitation. Tropical storm events associated with specific discharge peaks also are noted.

Winds were sustained from the south for an extended period of time with few fluctuations from mid-May 2004 through mid-August 2004, which was a period characterized by low discharge. Another period of sustained southerly winds was recorded in August 2003. Outside of these two periods of predominantly southerly winds, the wind direction was variable, but generally out of the north-northeast. Six of the sampling cruises were preceded by the variable, mainly north northeast wind periods, while the two remaining sampling cruises were preceded by the southerly blowing winds (Figure 5).

Total Suspended Solid Concentrations

Depth-averaged mean Total Suspended Solid (TSS) concentrations typically ranged from 10 to 20 mg L^{-1} during the study (Figure 10). Much higher concentrations were periodically observed at sites 1 and 2 where mean concentrations could reach as high as 43 mg L^{-1}. Although not consistent, TSS at sites 1 and 2 were frequently greater than concentrations reported for other sites further off- and alongshore. Maximum concentrations at sites 1 and 2 were observed in January 2004. March and September 2004 also yielded elevated concentrations. The mean TSS concentrations at the other sites fluctuated between 10 and 20 mg L^{-1}, with slightly higher overall concentrations occurring during the March 2004 sampling cruise.

When TSS concentrations were examined by discrete depths (Figures 11A-G), concentrations were uniform with depth at most sites for most sampling events. Only site 2 continuously exhibited significant differences in TSS concentration with depth (Figure 11B). At site 2, TSS concentrations near the bottom consistently exceeded concentrations measured higher in the water column. Sites 1 (control), 6, and 9 periodically showed stratification in TSS concentration (Figures 11A, D, G) and again higher concentrations were noted in bottom or middepth samples. The remaining sites, 5, 7 and 8 (Figures 11C, E-F) exhibited neither high temporal variability nor vertical stratifications in TSS concentrations with depth.

Sediment Composition

Sediment grab samples collected at sites 1, 5, 8, and 9 generally had low mud content, less than 4%, and usually changed by less than 1% from one set of samples to those collected during the next sampling period (Figure 12A). Sites 1 and 9, however, did exhibit small increases in mud content in September 2004, and site 5 exhibited elevated mud content in November 2004. Site 6 exhibited elevated mud content during three sampling cruises, September 2003, November 2003 and September 2004, while mud contents of similar magnitude were observed at site 7 in November 2003 and March 2004. Sediments collected at site 2 displayed the highest percent mud content of all sites during five of the eight sampling events, and was also the most variable of the seven sites, ranging from less than 5% in March 2004 to more than 98% in January 2004. In addition to the extremely high mud content observed in January 2004, samples from site 2 also contained elevated levels of mud in May 2004 and November 2004. September 2004 was the only month in which several different sites had concurrent mud peaks with sites 1 and 9 reaching their highest observed mud content during the study, and sites 2 and 6 reaching their second highest observed values.

The organic content of bottom sediments was usually less than 6% and fairly consistent at sites 1, 5, 7, 8, and 9 over the duration of this study (Figure 12B). The highest organic content observed occurred at site 2 in January 2004 when organic content exceeded 14%. Elevated organic contents also occurred at site 2 in May and September 2004. The site with the next highest organic content was site 6, which displayed increased organic content in bottom sediment

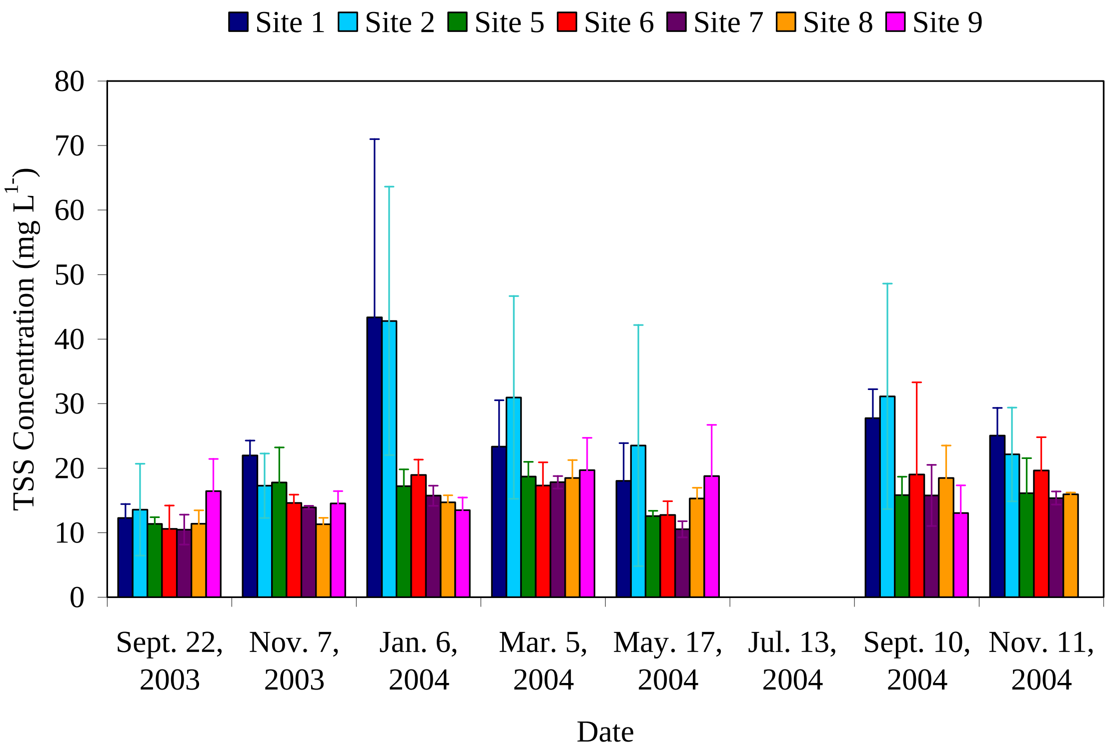
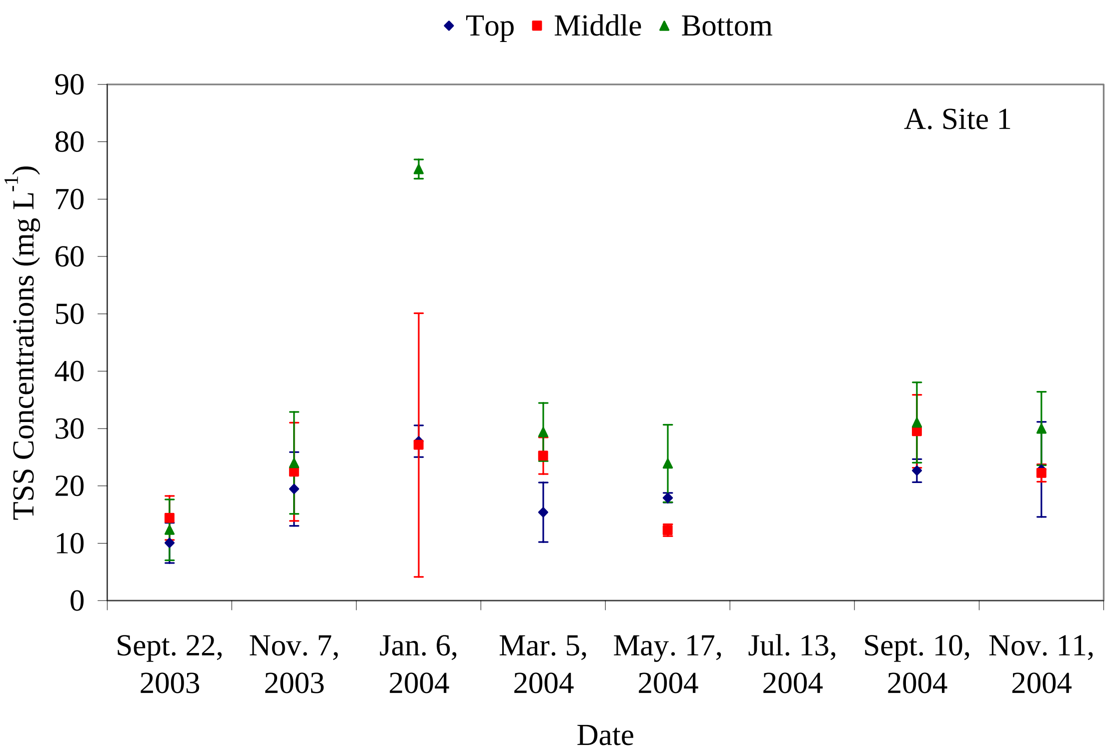
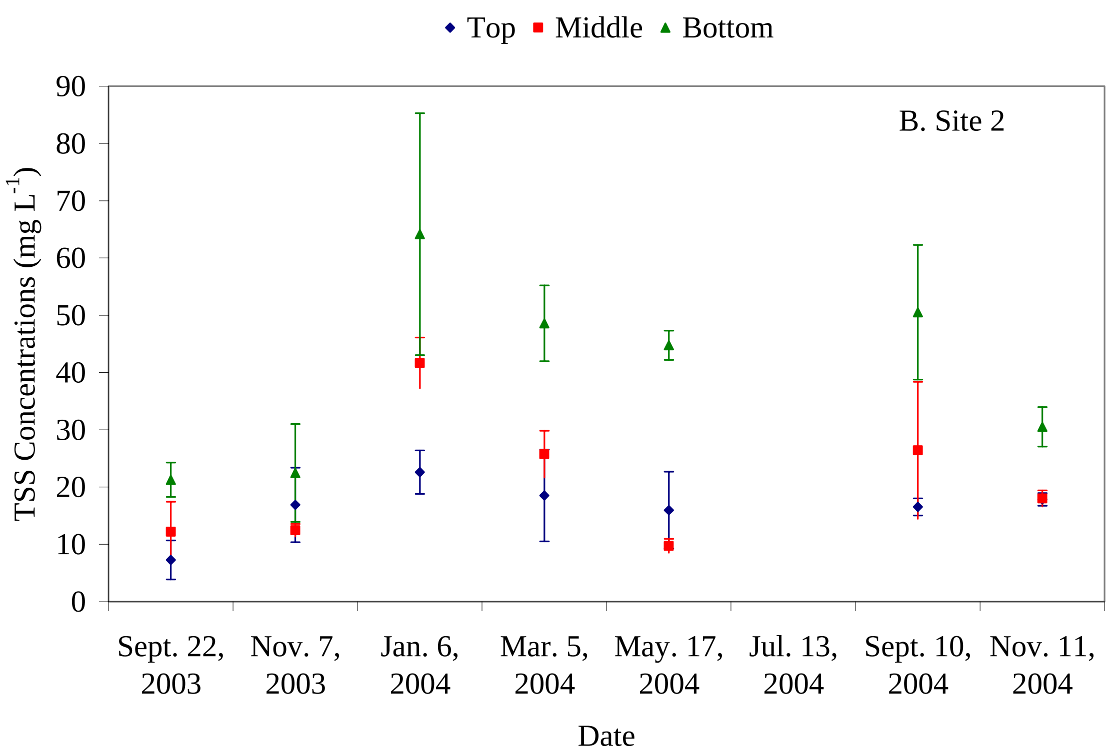
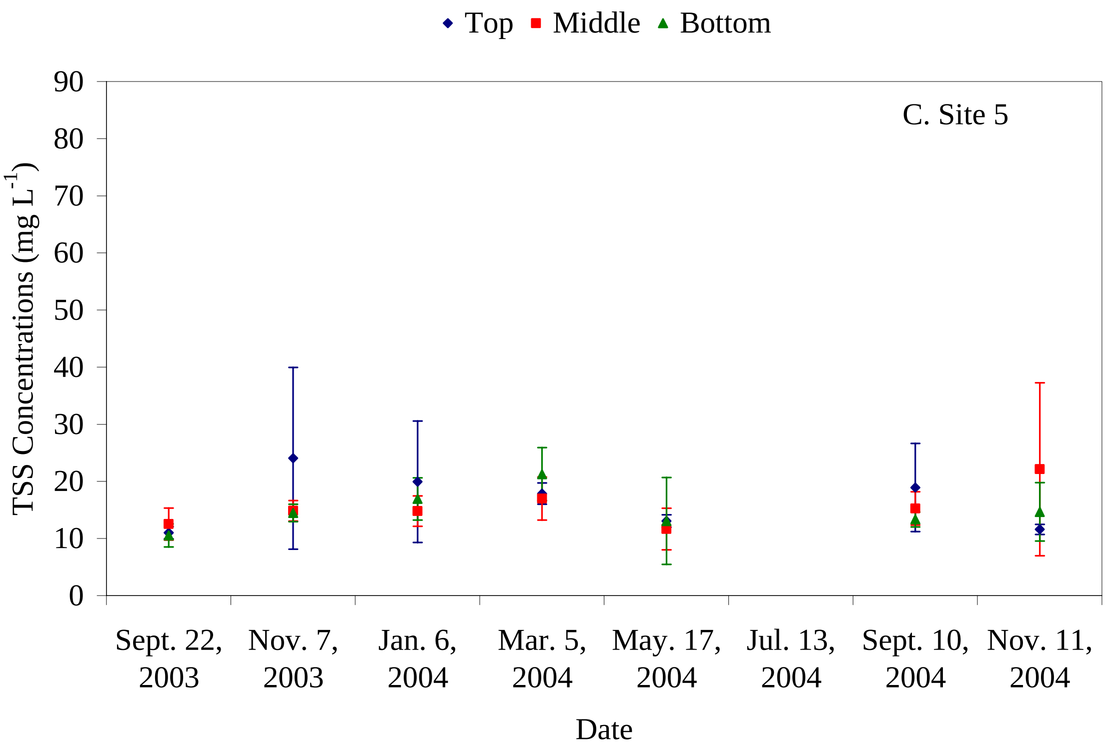


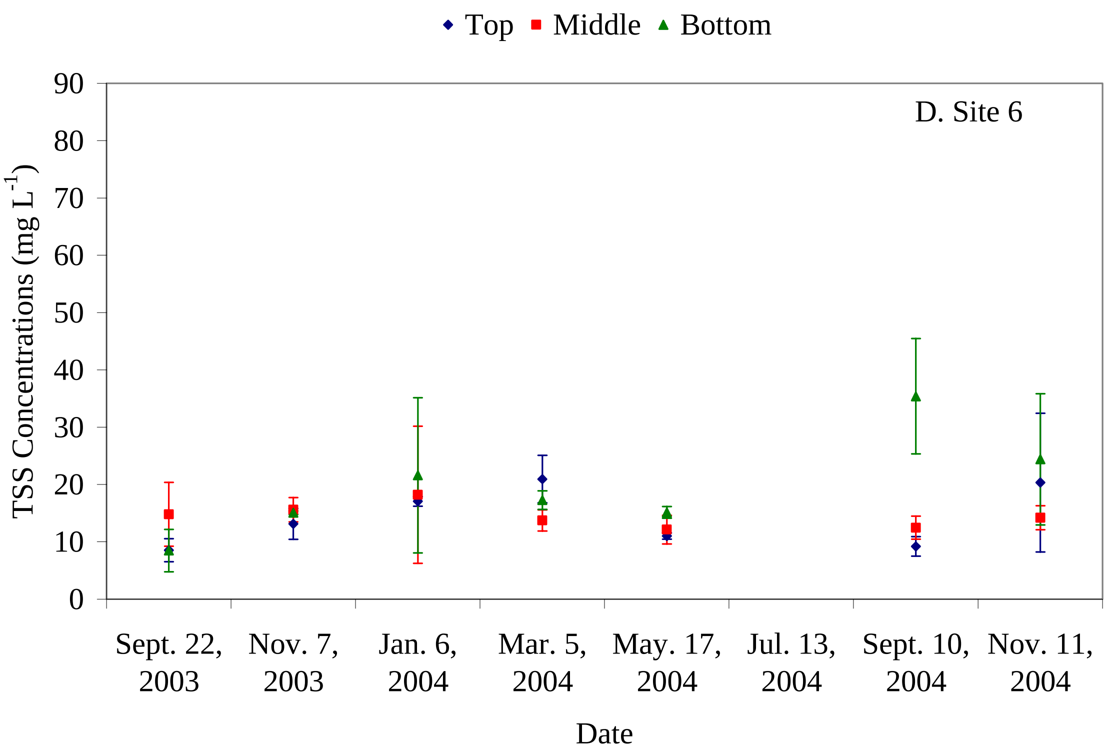
Figure 10. Depth-averaged mean TSS concentrations. July samples were lost due to an equipment malfunction in the laboratory. Error bars show one standard deviation from the mean.

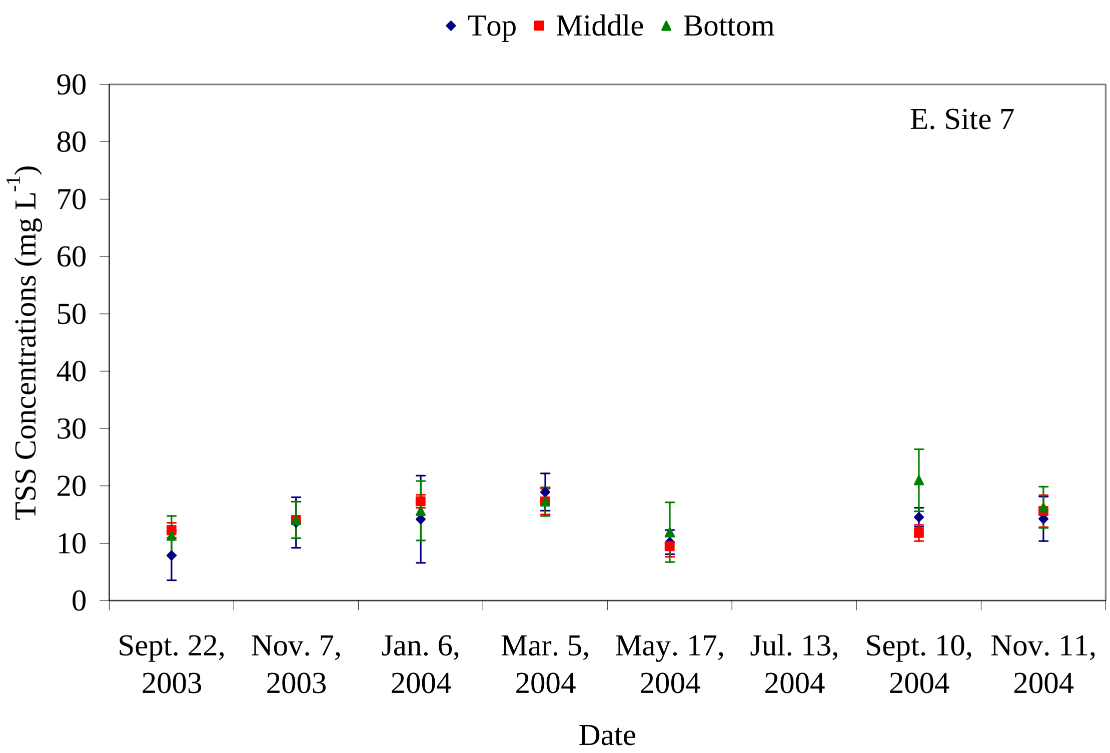
Figure 11. TSS concentrations by depth for each sampling site. Samples from July were lost due to equipment malfunction in the laboratory. A.) TSS concentrations at site 1 (control) B.) TSS concentrations at site 2, C.) TSS concentrations at site 5, D.) TSS concentrations at site 6, E.) TSS concentrations at site 7, F.) TSS concentrations at site 8, and G.) TSS concentrations at site 9. The error bars show one standard deviation from the mean for each depth.

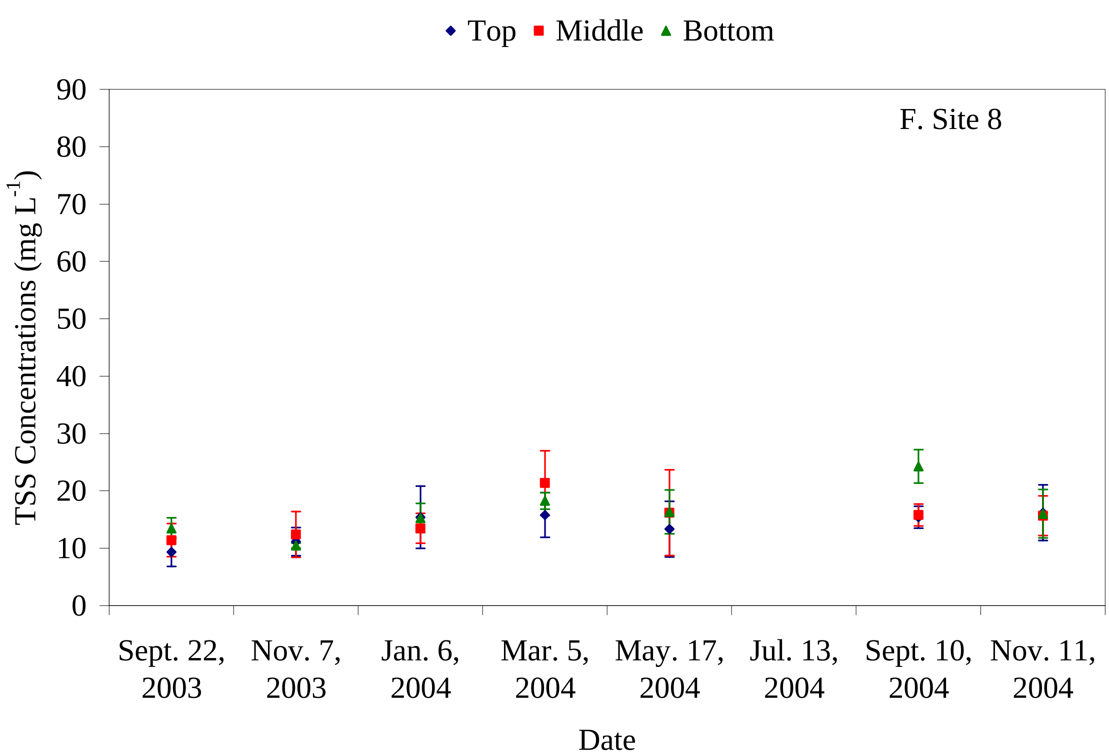

Top
Middle
Bottom
A. Site 1
TSS Concentrations (mg L-1)
0
10
20
30
40
50
60
70
80
90
Sept. 22, 2003
Nov. 7, 2003
Jan. 6, 2004
Mar. 5, 2004
May. 17, 2004
Jul. 13, 2004
Sept. 10, 2004
Nov. 11, 2004
Date

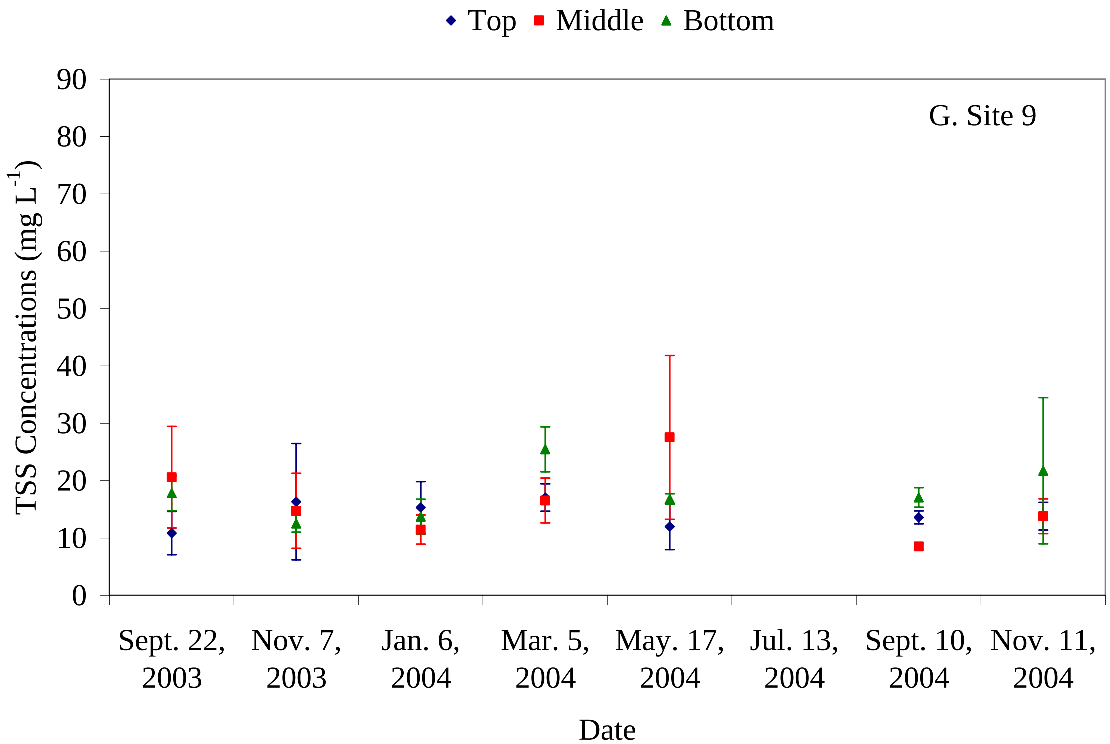

Top
Middle
Bottom
B. Site 2
TSS Concentrations (mg L-1)
0
10
20
30
40
50
60
70
80
90
Sept. 22, 2003
Nov. 7, 2003
Jan. 6, 2004
Mar. 5, 2004
May. 17, 2004
Jul. 13, 2004
Sept. 10, 2004
Nov. 11, 2004
Date


Top Middle Bottom
C. Site 5
TSS Concentrations (mg L-1)
90
80
70
60
50
40
30
20
10
0
Sept. 22, 2003
Nov. 7, 2003
Jan. 6, 2004
Mar. 5, 2004
May. 17, 2004
Jul. 13, 2004
Sept. 10, 2004
Nov. 11, 2004
Date


Top Middle Bottom
D. Site 6
TSS Concentrations (mg L-1)
90
80
70
60
50
40
30
20
10
0
Sept. 22, 2003
Nov. 7, 2003
Jan. 6, 2004
Mar. 5, 2004
May. 17, 2004
Jul. 13, 2004
Sept. 10, 2004
Nov. 11, 2004
Date


Top
Middle
Bottom
E. Site 7
TSS Concentrations (mg L-1)
90
80
70
60
50
40
30
20
10
0
Sept. 22, 2003
Nov. 7, 2003
Jan. 6, 2004
Mar. 5, 2004
May. 17, 2004
Jul. 13, 2004
Sept. 10, 2004
Nov. 11, 2004
Date


Top
Middle
Bottom
F. Site 8
TSS Concentrations (mg L-1)
90
80
70
60
50
40
30
20
10
0
Sept. 22, 2003
Nov. 7, 2003
Jan. 6, 2004
Mar. 5, 2004
May. 17, 2004
Jul. 13, 2004
Sept. 10, 2004
Nov. 11, 2004
Date



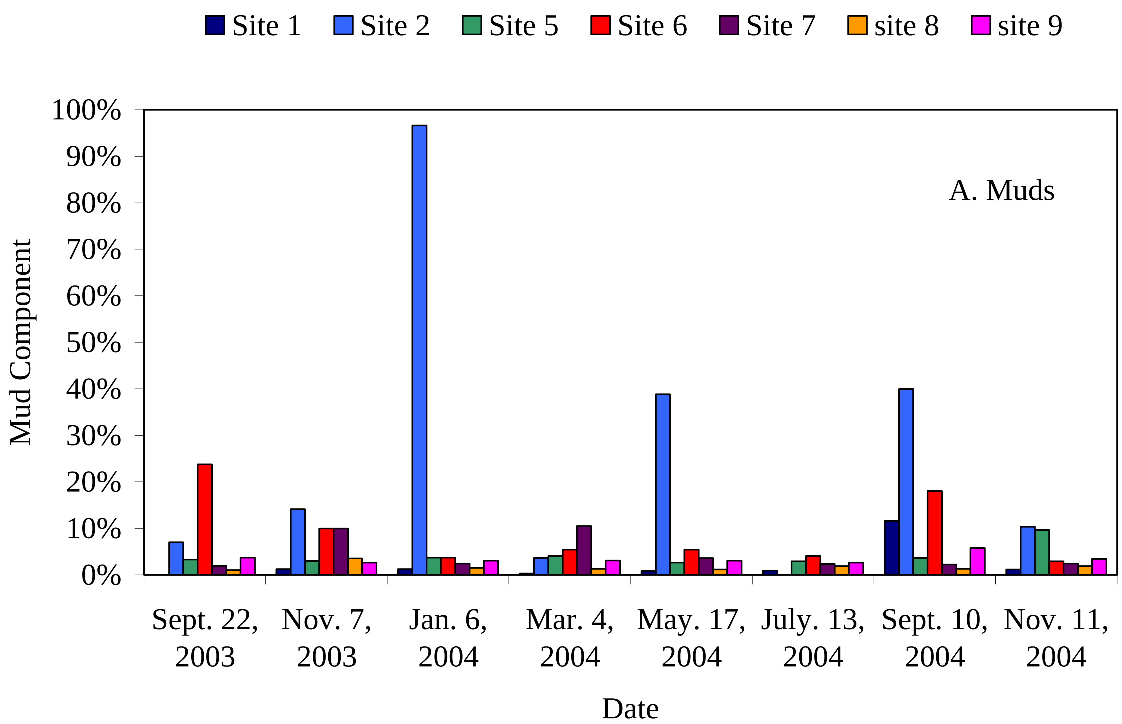
Top
Middle
Bottom
G. Site 9
TSS Concentrations (mg L^{-1})
90
80
70
60
50
40
30
20
10
0
Sept. 22, 2003
Nov. 7, 2003
Jan. 6, 2004
Mar. 5, 2004
May. 17, 2004
Jul. 13, 2004
Sept. 10, 2004
Nov. 11, 2004
Date

in September 2003 and September 2004. No appreciable changes in organic content were observed at the other sites with the exception of very subtle increases at sites 5, in November 2004, and site 7, in March 2004 (Figure 12B).

Correlation Analysis

Correlation analyses were conducted to determine if the TSS concentrations at each site were significantly associated with TSS concentration measured at the river control site (site 1). These analyses resulted in two positive, significant correlations with mean TSS at site 1 (Table 1A, Appendix A); site 2 ($r=0.90$, $p=0.006$) and site 6 ($r=0.76$, $p=0.046$). The mean TSS concentrations at other sites were not significantly correlated with mean TSS concentration at site 1. Possible correlations between mean TSS organic concentrations were also explored. These analyses resulted in three significant correlations, site 2, site 6 and site 7 (Table 1B). Site 2 exhibited a weak, positive correlation with site 1 ($r=0.89$, $p=0.007$) as did site 7 ($r=0.83$, $p=0.020$), while site 6 had a strong positive correlation ($r=0.94$, $p=0.002$) (Table 1B, Appendix A).

Stratification of TSS concentrations were periodically observed, so in addition to correlating depth-averaged mean TSS concentrations to mud content of bottom sediments, TSS concentrations at discrete depths were also correlated to the mud content of bottom sediments (Table 2A-E, Appendix B). These analyses yielded four significant correlations. Only site 2, located closest to the river mouth, showed a positive and significant correlation between the depth-averaged mean TSS and mud content ($r=0.78$, $p=0.039$) (Table 2A). The remaining three significant correlations were associated with TSS concentrations measured at discrete depths at sites 2, 5, and 6. At site 6, TSS concentrations in surface waters were positively correlated with



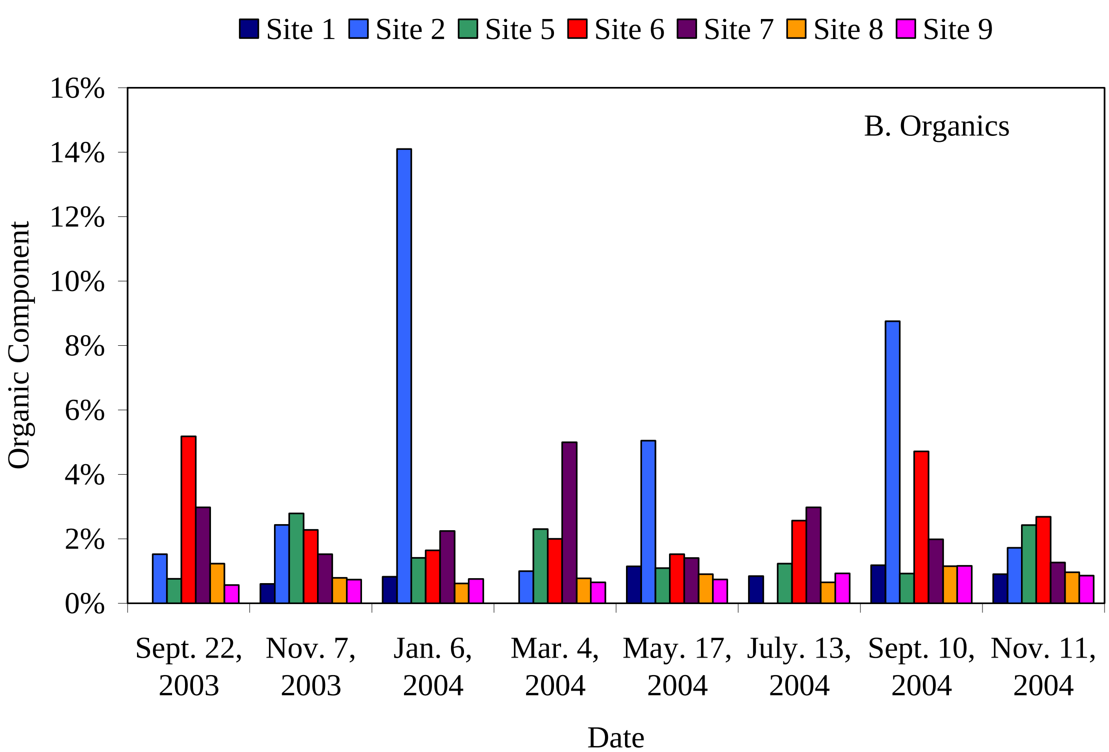


Figure 12. Variations in sediment components over time. Change in mud (A) and organic composition (B) at all sites. Bottom sediments could not be sampled at site 1 in September 2003 and site 2 in July 2004.

percent mud content in bottom sediments (r=0.79, p=0.035) (Table 2B). At site 5, percent mud content was positively and significantly correlated to TSS concentrations in the middle of the water column (r=0.92, p=0.003) (Table 2C). At site 2, the percent mud content of bottom sediment was significantly correlated with TSS concentrations at the bottom of the water column (r=0.77, p=0.048) (Table 2D). The percent organic component of the bottom sediments was then correlated with the depth-averaged mean organic TSS concentrations yielding a significant relationship at only site 2 (r=0.86, p=0.012) (Table 2E).

When examined by individual sampling site, sites 2 (r=0.97, p=2.2E-04) and 6 (R=0.91, p=0.002) (Table 3A, Appendix C) showed a significant positive correlation between mud content and organic content of bottom sediments. The associations at these two sites led to examination of all sites based on aforementioned pairings; routinely influenced (2 and 6), occasionally influenced (5 and 7), and rarely or never influenced (8 and 9). When paired, sites 2 and 6 demonstrated a highly significant positive correlation (r=0.96, p=8.71E-09) between the mud and organic content of the bottom sediments (Table 3B). Sites 5 and 7, when paired, and sites 8 and 9 when paired did not demonstrate any significant correlations (Table 3B). Site 1, as the control site, was not grouped.

Table 1. Results of correlation analyses between TSS concentrations at control and other sampling sites. A.) r and p-values from correlation analysis of mean TSS concentrations at each sampling site to mean TSS concentrations at the control site 1. B.) r and p-values from correlation analysis of mean TSS organic concentrations at each sampling site to mean TSS organic concentrations at the control site 1. Values in italics were significant at $p < 0.05$.

A.	r	p-value
Site 2	*0.90*	*0.006*
Site 5	0.59	0.162
Site 6	*0.76*	*0.046*
Site 7	0.62	0.140
Site 8	0.31	0.492
Site 9	0.54	0.210
B.		
Site 2	*0.89*	*0.007*
Site 5	0.17	0.724
Site 6	*0.94*	*0.002*
Site 7	*0.83*	*0.020*
Site 8	0.06	0.892
Site 9	0.58	0.174

Table 2. Results of the correlation analyses of sediment constituents and TSS concentrations. A.) Mud and depth averaged mean TSS concentrations: B.) Mud and TSS concentrations at the surface of the water column C.) Mud and TSS concentrations at the middle of the water column. D.) Mud and TSS concentrations at the bottom of the water column. E.) Percent organic content of bottom sediments and depth-averaged, mean organic TSS concentrations. Values shown in italics were significant at $p < 0.05$.

A.	r	p-value
Site 1	0.10	0.855
Site 2	*0.78*	*0.039*
Site 5	0.18	0.694
Site 6	0.51	0.245
Site 7	0.37	0.411
Site 8	0.47	0.288
Site 9	0.39	0.389
B.		
Site 1	0.25	0.637
Site 2	0.58	0.174
Site 5	0.41	0.360
Site 6	*0.79*	*0.035*
Site 7	0.57	0.185
Site 8	0.23	0.621
Site 9	0.32	0.482
C.		
Site 1	0.52	0.288
Site 2	0.72	0.068
Site 5	*0.92*	*0.003*
Site 6	0.20	0.674
Site 7	0.34	0.451
Site 8	0.32	0.478
Site 9	0.47	0.293
D.		
Site 1	0.08	0.874
Site 2	*0.77*	*0.049*
Site 5	0.10	0.834
Site 6	0.10	0.827
Site 7	0.03	0.947
Site 8	0.57	0.178
Site 9	0.06	0.906
E.		
Site 1	0.42	0.406
Site 2	*0.86*	*0.012*
Site 5	0.50	0.253
Site 6	0.12	0.796
Site 7	0.17	0.716
Site 8	0.62	0.136
Site 9	0.33	0.473

Table 3. Results of correlation analyses between percent organic content and percent mud content of bottom sediments. Results are shown for each site individually (A) and for site pairs based on the proximity of each site to the mouth of the CFR (B). Values shown in italics were significant at $p < 0.05$.

A.	r	p-value
Site 2	*0.97*	*2.20E-04*
Site 5	0.44	0.280
Site 6	*0.91*	*0.002*
Site 7	0.40	0.330
Site 8	0.36	0.390
Site 9	0.63	0.090
B.		
Sites 2 and 6	*0.96*	*8.71E-09*
Sites 5 and 7	0.40	0.125
Sites 8 and 9	0.05	0.844

DISCUSSION

Sampling Site Proximity to Cape Fear River Mouth

The main objective of this study was to determine if total suspended solids transported to the coastal ocean by the CFR exert any detectable effect on the texture of sediment deposits deposited on the inner shelf in Long Bay. Thus, the sampling sites were grouped according to whether they were expected to be routinely influenced by the river (sites 2 and 6), occasionally influenced by the river (sites 5 and 7) or rarely to never affected by the river (site 8 and 9). Site 1, as the river control site was not grouped.

The highest TSS concentrations were observed at sites closest to the river mouth and presumed to be routinely influenced by the river (sites 2 and 6) and also at the control site (site 1). Sites 1, 2, and 6 account for the highest mean TSS concentrations observed for six of the eight sampling events while the highest mean TSS concentrations for the entire study were observed at site 2 in four of the eight sampling events. Depth-averaged TSS concentrations at the control site (site 1) and site 2 were more variable than the other five sites, at times changing more between consecutive sampling periods than other sites changed over the entire study. Site 6 showed a similar pattern of variability, although not to the magnitude observed at sites 1 and 2. In general site 1, 2, and 6 exhibited the greatest vertical variability in TSS concentration and highest concentrations when samples were collected after a peak discharge event (i.e. January and September 2004). For these events, the highest concentrations usually occurred in near bottom samples. The timing of other peak discharge events did not coincide with or precede high TSS concentrations (i.e. August and October 2003 and May 2004). Further, TSS concentrations at site 2 occasionally were higher than those at site 1 possibly due to secondary influence from an unobserved source (such as resuspension). Despite high TSS concentrations not being coincident with some peak discharge events, the similarity in temporal and vertical TSS concentration patterns between site 1 (the control site positioned in the mouth of the CFR) and sites 2 and 6 suggest that mean TSS concentrations at these innermost shelf sites are influenced to some degree by TSS concentrations in the river (Table 3). The remainder of the sites showed little if any variation temporally or spatially, presumably due to their distance from the river mouth.

The TSS concentration results are consistent with Kim and Voulgaris (2004) who also reported more highly variable suspended solid concentrations (SSC) at sites 1, 2, and to a lesser extent at site 6. The remaining sites showed very little, if any, variability with depth or over time. Kim and Voulgaris (2004) also reported that sites 1, 2, and 6 showed stratification with SSC concentrations at the bottom of the water column being consistently higher than those measured at the surface. Because the LSST also reports grain size parameters of suspended particles, Kim and Voulgaris (2004) were able to document a general seaward coarsening of suspended particles across sites utilized in the present study. These results may suggest that 1) muds from the river are not usually reaching offshore sites, 2) material in suspension offshore is due to resuspension of another source-possibly shoals or resuspension of the thin sand veneer.

Significant positive correlations between both depth-averaged mean TSS concentrations and depth-averaged mean TSS organic concentrations at the control site (site 1) and sites 2 and 6 suggest that sites 2 and 6 are directly and routinely influenced by suspended material carried by the river (Table 1A-B). This result was expected given the close proximity of sites 2 and 6 to the river mouth and reports of prevailing currents in the area, which are highly tidal and flow strongly in the onshore/offshore direction in the vicinity of these sites (McNinch, 2004). When depth-averaged mean TSS concentrations and depth-averaged mean TSS organic concentrations at the offshore sites were correlated against the control (site 1), only depth-averaged mean TSS organic concentrations at site 7 were significantly correlated with site 1 (Table 1B).

Textural and Compositional Changes in Bottom Sediment

Mud content was generally low and consistent for most of the sampling sites, with sites 1, 5, 8 and 9 rarely exhibiting mud content in excess of 5%. Site 1, located in the mouth of the river, would be subjected to strong riverine flow as the water is forced out the river mouth, which could inhibit settling of fine particles or winnow out any mud that may have been previously deposited. Thus, the low mud content of bottom sediments observed at site 1 was expected. The mud content patterns observed for sites 8 and 9 were also expected since these sites were distal from the river mouth and not theorized to be appreciably affected by fine-grained materials presumably delivered by the river. Site 8, however, is located adjacent to Lockwood's Folly Inlet, which could provide a potential secondary freshwater source (Kim and Voulgaris, 2004) and source of additional sediment. Despite this, bottom sediment compositional and textural changes at site 8 were among the least dynamic in the study. Site 5 lies directly between sites 6 and 8, which is nearly the midpoint between Lockwood's Folly, from which discharge has been known to flow east up the coast (Alphin, pers. comm.), and the mouth of the CFR. As a result, it is probable that sediment dynamics at site 5 are influenced by both the CFR and Lockwood's Folly. The three sites showing the most fluctuations (2, 6, and 7) in mud content of bottom sediments are also the sites closest to, or directly in the path of, the outflow from the river and aligned with the direction of the tidal currents which dominate circulation in the area (McNinch, 2004).

Changes in percent mud of bottom sediments were correlated to depth-averaged mean TSS concentration to determine any impact that TSS concentrations exerted on the bottom sediment composition and texture (Table 2A-D). TSS concentration and mud content were significantly correlated for sites 2, 5, and 6. Site 5 exhibited the strongest association of any of the sites with a significant and positive correlation between mud content and TSS concentrations measured in the middle of the water column ($r=0.85$, $p=0.003$). It is at this level (middle) of the water column at site 5, near the pycnocline, that Kim and Voulgaris (2004) hypothesized that flocculation was occurring in the water column leading to slight increases in grain size that facilitate settling. If occurring, this mechanism provides one possible explanation for the significant correlation observed between mid-water TSS concentration and increased mud content at site 5. Data collected at site 2 showed a significant positive correlation between both depth-averaged mean TSS ($r=0.61$, $p=0.039$) and near bottom TSS concentrations ($r=0.59$, $p=0.049$) and percent mud content. Since TSS concentrations at site 2 were associated with TSS concentrations at the control site, the correlations, though weak, between TSS concentrations and mud content at site 2 suggest a possible association between deposited sediment at site 2 and river derived material. The same observation applies to site 6, where mud content of bottom sediment was also weakly and positively correlated ($r=0.62$, $p=0.035$) with near surface TSS concentrations. Organic content of bottom sediment was significantly and positively correlated ($r=0.74$, $p=0.012$) to depth-averaged mean TSS organic content at site 2 (Table 2E). No other significant relationships were found when comparing these deposited and suspended organics.

The bottom sediments at site 2 exhibited a wide range of mud content from a low of nearly 4% in March 2004 to a maximum of nearly 96% in January 2004. Another period of increased mud (near 40%) content persisted from May 2004 to September 2004 and was followed by another dramatic decrease to near 10% in November 2004. The pattern of increasing and decreasing mud mirrors TSS fluctuations observed at site 2. While it is possible that the observed variations in bottom sediment composition may be due to changes in composition and concentration of water column material, it is also possible that changes in TSS may be resulting from resuspension of sediment on the bottom during intense and prolonged current or wave events. Such processes might account for the high concentrations of TSS frequently observed in the bottom of the water column during the study. Unfortunately, insufficient physical data exist within the study area to quantify bottom stresses and assess the potential for resuspension over the study period. A qualitative overview of wind and wave data reported from Frying Pan Shoals, approximately 20 km Southeast of the study area (55 Km from mouth), does not indicate a consistent influence on the TSS concentrations measured during this study (Figure 5). For example, while distinctly higher TSS concentrations were measured near bottom at site 2 for the January, March, May, September, and November 2004 sampling events, the only time preceded by increased wave activity was potentially in January when wind speeds on the order of 10 m s^{-1} may have produced waves capable of resuspending material. Unfortunately, the wave gauge at Frying Pan was not reporting at that time. For the other high TSS events, wave heights did not exceed 2.3 m prior to sampling. While these results do not exclude resuspension as a possible source, the significant positive correlation between TSS concentrations at the river control and at site 2 as well as the correlation between mud and organic content at site 2 would suggest that sedimentary material at site 2, is influenced by a river derived component.

The lack of association between TSS concentrations (both depth averaged mean and mean organic) and bottom sediment composition at any of the sites except for site 2 may be a result of an unobserved, temporal settling lag. When suspended sediment is discharged from the river, the coarsest, most settleable fraction is deposited first and in close proximity to the mouth. The finer material is ultimately carried further from the source since it requires considerably more time to settle. Due to the sampling frequency employed during the study, however, it is not possible to verify the existence of such a phenomenon. Should a settling lag exist such as documented in it might explain why sites 2 close to the river mouth and the main channel, such as site 2 exhibited the only significant correlation between suspended and deposited sediments.

Data collected at site 7, provide qualitative evidence in support for a potential lag between TSS concentration and bottom sediment attributes due to transport mechanisms. The increase in mud content of bottom sediments collected at site 7 in November 2003 and March 2004 may have been the result of the plume shifting its orientation from site 6 (where high mud content was observed in September 2003) towards site 2 where elevated mud content was observed in January 2004. Reworking and transport of the muds from site 2 to the west south-west by ephemeral currents flowing over Frying Pan Shoals from Onslow Bay (such as described in Schumacher and Korgen, 1974), could account for the increased mud content observed at site 7 in March, but not at site 2 or other sites closer to the river mouth. This mechanism could also explain how mud content at site 7 could increase in the absence of increased TSS concentrations in the water column. No instrumentation was available over the course of this study to monitor such a flow, but the phenomenon has been observed in the vicinity of the CFR plume (Shumacher and Korgen, 1974).

Source of Material

As outflow from the CFR moves off-, or along-shore in upper Long Bay, the largest and highest density particles suspended in the water column begin to settle rapidly due to a decrease in energy of the river outflow, and due to interactions with waves and currents. Smaller and lighter particles, especially organic aggregates, have the potential to be transported furthest offshore due to their low settling velocities. TSS concentrations at those sites closest to the river mouth should, therefore, show the highest and most variable concentrations of TSS as they would be the most directly affected by river effluent. This phenomenon was, in fact, observed during this study to a great degree at sites 1 (control) and 2. Because suspended sediments carried in the river may be derived from a variety of sources (Raber, 2004) and because river discharge is strongly influenced by both black water and brownwater inputs (Mallin, 2004), the composition of suspended material flowing out of the river and deposited on the inner shelf is highly variable. The data presented here confirm a high degree of temporal and spatial variability in texture and composition among the sites examined and also suggest that the mediating effects of processes not directly examined also affect temporal and spatial trends. As a result, precisely identifying the ultimate source of the muds periodically observed on the inner shelf is a complicated process.

Based on preexisting studies of the underlying geologic framework conducted in regions near the study area, the mud drapes observed in Long Bay have two potential sources. First, they may be derived from reworking of relict sediment or second, they could be produced through deposition of material from effluent of the Cape Fear River. In cores described by Meisburger (1979), muddy sands were identified in a few locations in Long Bay well south and seaward of the sites sampled during this study. These deposits, however, were not identified as containing organic material. Meisburger (1979) also described more mud-rich deposits at depth (more than 1 m), but these deposits were not organic-rich such as those observed at sites near the river mouth during the present study. Further, these buried deposits are found at depths of 1-5 meters making it unlikely that they would be readily available for reworking under the range of physical conditions present in the area.

During this study, the percent organic constituent and mud content of bottom sediments was significantly and positively correlated for samples collected at the two sites (sites 2 and 6) closest to the mouth of the river (r=0.93, p=8.71E-9).   The other sites, when paired by potential river impact as defined earlier, showed no such correlation. These results suggest that 1) the muds observed in the study are derived from an organic source and 2) that a likely source of these muds, given the spatial distribution, is the river. These observations are consistent with conclusions by Cleary (1996) who reported that the muds observed in Long Bay are most likely derived form material brought to the coast by the Cape Fear River.

Though a relationship between the sites more proximal to the CFR mouth and material coming from the river seems apparent based on the correlation analysis (Table 1A-B and Table 3 A-B), another possible non-river source may be relict, organic-rich muds in the vicinity reworked from ancient river channels and marsh environments. Extensive deposits of this type, however, have not yet been identified in bottom grab sample surveys, box core surveys, or observed by divers in the study area.

In spite of the apparent influence of river input on total suspended sediment concentration and bottom mud content, no discernable relationship existed between river discharge and TSS concentration or mud content. The result may be due to the limited data set available for this study. The bi-monthly sampling employed during this study is of insufficient frequency to definitively identify response lags between factors such as discharge and mud content. The processes impacting sediment characteristics frequently occur over much shorter time scales ranging from monthly, bi-weekly, weekly, or even daily. It is apparent, too, that there are two possible source-locations for precipitation that provides run-off, and direct water inputs in the drainage basin. Precipitation in the upper portion of the drainage basin, monitored at Greensboro airport and the lower portion of the drainage basin as monitored at Lock and Dam #1 may both influence discharge at the mouth. More frequent sampling, over a longer time period, would allow for a better picture as to whether there is any relationship between the precipitation, discharge and TSS concentrations. Based on observed textural variability of bottom sediments, any presumed movement of muddy material is speculative at best since sufficient data on mechanisms for such transport were lacking during the study period. Current profiles in the bottom boundary layer and directional wave spectra are needed to fully describe the sediment dynamics of this inner shelf region. In addition, high resolution remote sensing data would also be helpful in visually tracking the optical plume, though no images with fine enough resolution could be located.

CONCLUSIONS

The hypothesis of this study that the presence and distribution of muds in inner Long Bay is coincident with increased TSS concentrations in the Long Bay following periods of peak river discharge, was partially supported by the findings of the study. Though it does appear that TSS concentrations in the water column have some impact on the textural make-up of those sites most proximal to the river mouth (sites 2 and 6), no similar relationship became apparent for those more distal sites. In addition the positive correlations between organic and mud content of bottom sediments at these same two sites also strongly support the CFR as a source.

The available data made it difficult to describe the exact nature of the other sites. Though no statistical data were able to relate site 7 to the river derived material, its location seaward and within the path of the river channel and periods of heightened mud content make this site of increased interest. It is likely that the textural changes at site 7 are related to textural changes at sites 2 and 6, since mud content peaks at site 7 were always preceded by mud content peaks at one of the other two sites.

Sites 5 and 8 are possibly impacted by input from Lockwood's Folly, thereby complicating the sediment patterns observed at these sites. Further, because no physical data are available for discharge at Lockwood's Folly, it is difficult to describe possible impacts this secondary effluent may have had on these sites. Sites 5 and 8 may be in the plume at times, but variations in wind direction made any exact approximation of plume orientation difficult. There was some evidence that the inorganic portion of the muds were transported as far offshore as site 9 following high and prolonged periods of discharge, though, usually this distal site did not appear to be influenced by the river.

This project worked on many assumptions that should be addressed when examining the validity of the data contained within. First, these results assumed that samples were collected from precisely the same location each month. Though sampling was in the same general vicinity for each site, the drifting of the boat could have created errors in excess of 30 meters for repetitive sampling. It is possible that, if the mud deposits are permanent, that they were sampled some months and missed other months depending on the exact positioning of the boat and whether the grab drifted at an angle when dropped over the side of the boat. In addition, although sampling cruises were scheduled to coincide with an ebbing tide, the time required to collect samples sometimes led to some sites being sampled near low water or early flood tide. As a result, the currents that existed at time of sampling varied from cruise to cruise and may have affected some of the parameters measured during this study.

Current and wave data provided by an Acoustic Doppler Current Profiler (ADCP), could give some insight into the movement of suspended materials at each of the discrete depths in the water column, as well as any periods of resuspension in subsequent studies. In addition, an optical backscatterance sensor (OBS) would allow the continued monitoring the concentrations of materials in suspension. Discharge monitoring at Lockwood's Folly, as well as current data from the mouth of this freshwater source would allow for the elimination or incorporation of this secondary freshwater source to the variations we see at sites 5 and 8. Sampling could also be enhanced. Instead of sampling each site only on the way out from the mouth of the river, sampling could be conducted on the way back in and an additional site (an additional site triangulated between sites 2, 6, and 7) may assist the further description of processes at site 7 and further offshore. This information would help us determine the potential for movement of deposited sediments from one site to another.

Findings from this study that address specific objectives included are most easily understood when applied to the objectives presented in the introduction. As such the following summary addresses each of our goals and conclusions.

Objective 1: To determine spatial variations in inner shelf sediment texture and organic content and TSS concentration, and to determine if variability among these parameters is a function of proximity to the CFR mouth.

- The two sites most proximal to the mouth of the CFR (site 2 and 6) and site 1 (in the mouth of the river) are the most temporally and spatially variable in TSS concentrations, with the sites 2 and 6 also being the most temporally variable in sediment texture and composition.
- Site 7 then showed higher variability than did sites 5, 8 and 9, and though it is not as close to the mouth as site 2 and 6 it is located offshore approximately in the path of the main channel.
- Those sites more proximal to the CFR mouth do indeed show the most variability, while those four sites (sites 5, 7, 8, and 9) distal from the mouth of the CFR are much less variable except in the case of extratropical events.

Objective 2: To determine temporal variations in inner shelf sediment texture and organic content and in TSS concentration, and to relate these to river discharge and prevailing wind conditions.

- No strong correlations were evident to support any direct association between the discharge from the river and variations in TSS concentrations or textural and compositional bottom sediment traits, with only one significant correlation (at site 8) being evident.

•Wind direction proved difficult to use as a proxy for plume direction as no trend between direction and temporal changes in TSS concentrations or bottom sediment composition was observed, which may have alluded to an association between wind direction and sediment delivery.

Objective 3: To determine if changes in sediment texture or percent organic content are correlated with TSS concentration in the overlying water column and/or with elevated discharge from the CFR. If changes in texture or organic content are observed, but cannot be correlated with TSS or discharge, alternative mechanisms will be suggested for future study.

•Significant positive correlations linking TSS concentrations to changes in bottom sediment composition were only seen at sites 2, 5 and 6. Of these three, only site 2 demonstrated an association between the organics in the water column and in the surficial bottom sediments.

•Sites 5 and 6 only had correlations for specific discrete depths, while mud content at site 2 had was correlated with both depth-averaged mean TSS and TSS concentrations at the bottom of the water column.

•It seems then that a definite correlation exists between TSS concentrations and bottom sediment composition at site 2, while there is a chance of correlation at sites 5 and 6.

•More frequent sampling in conjunction with new equipment deployment (ADCP, OBS) could help fill in the gaps of data allowing for characterization of sites 5, 7, 8 and 9. It is possible that a secondary influence on sites 5 and 8 may be Lockwood's Folly.

Main Objective: To determine if total suspended solids transported to the coastal ocean by the CFR exerts any detectable effect on the texture of sediment deposits deposited on the inner shelf in Long Bay.

• There is evidence to suggest that sites proximal to the mouth of the Cape Fear River have TSS concentrations associated with material being transported by the river. For those four sites more distal from the mouth no significant correlation existed linking the sites to TSS concentrations at the mouth.

•Some evidence for river material influence at site 9 also exists during extreme extratropical events, but evidence is not strong enough to relate the mud seen at site 9 with extreme events.

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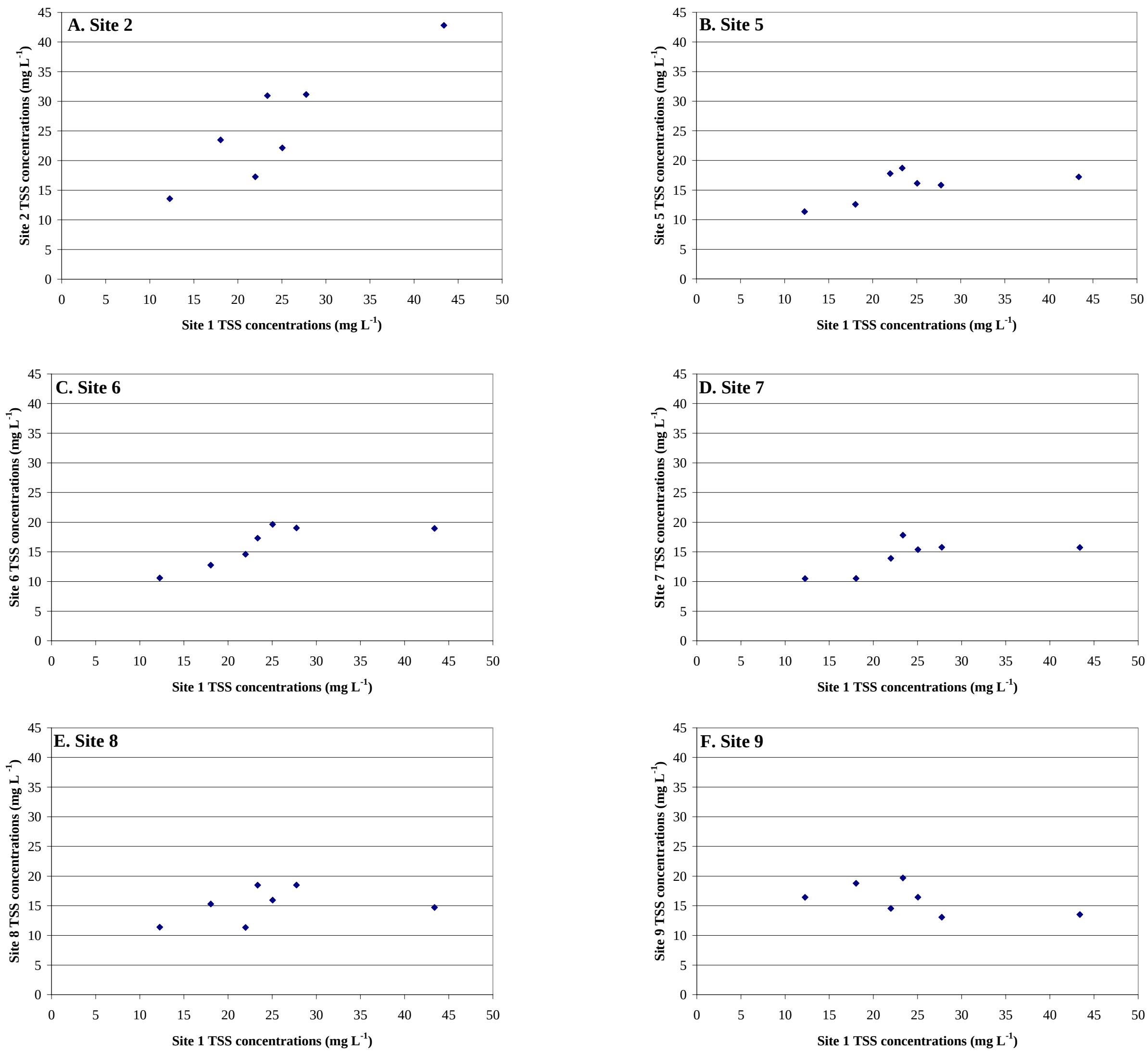
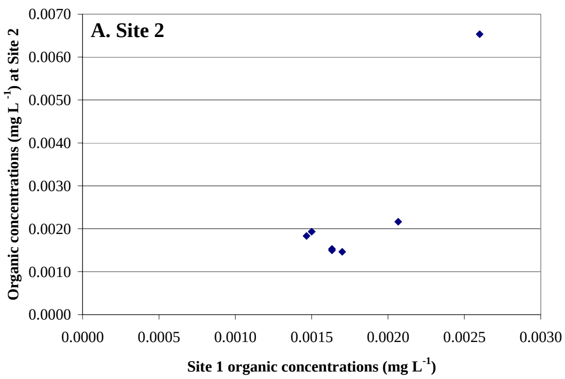
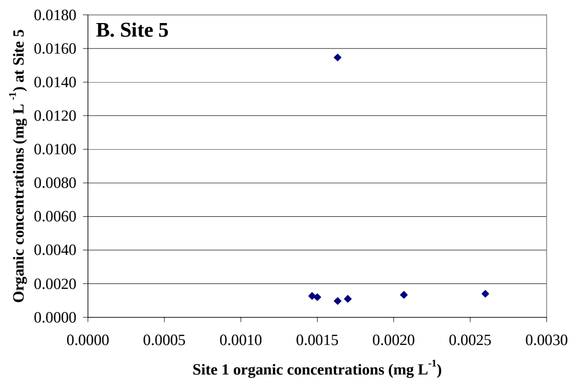
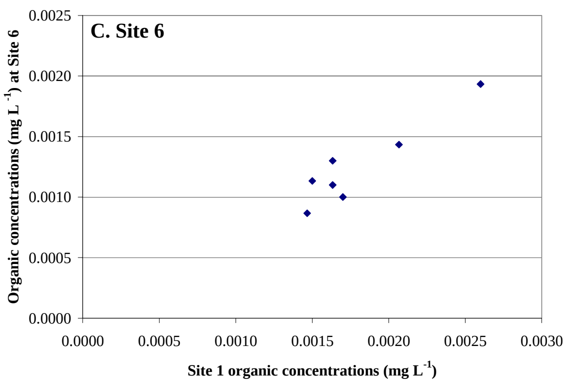
APPENDIX

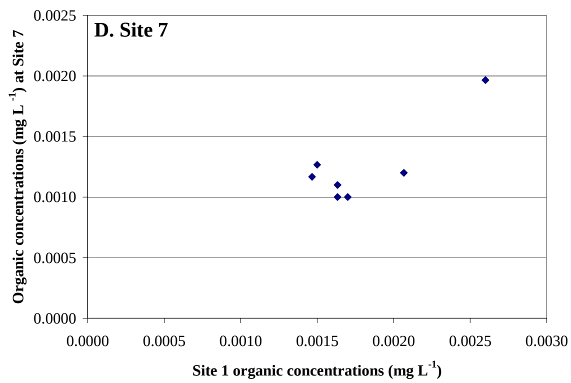
Appendix A. Scatter plots associated with Table 1

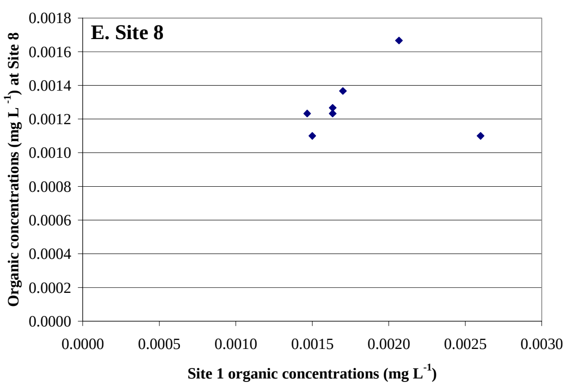


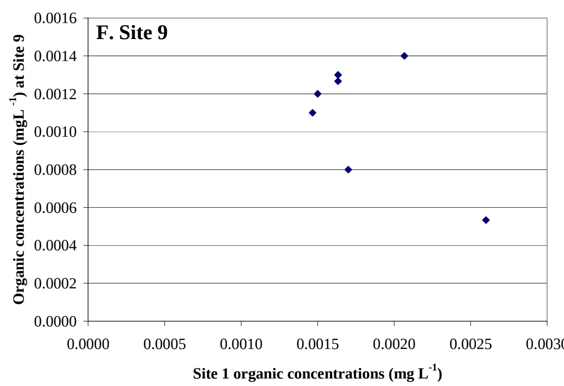

A. Site 2
Organic concentrations (mg L -1) at Site 2
0.0070
0.0060
0.0050
0.0040
0.0030
0.0020
0.0010
0.0000
0.0000 0.0005 0.0010 0.0015 0.0020 0.0025 0.0030
Site 1 organic concentrations (mg L-1)


B. Site 5
Organic concentrations (mg L -1) at Site 5
0.0180
0.0160
0.0140
0.0120
0.0100
0.0080
0.0060
0.0040
0.0020
0.0000
0.0000 0.0005 0.0010 0.0015 0.0020 0.0025 0.0030
Site 1 organic concentrations (mg L-1)

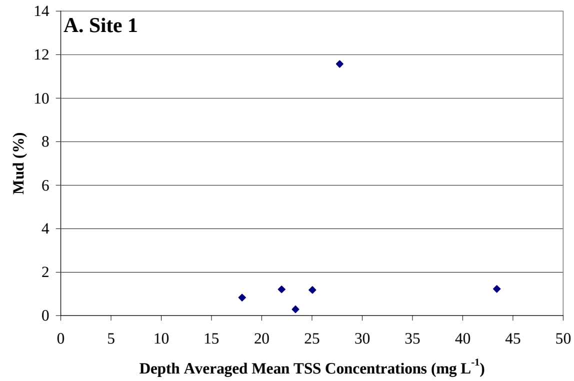

C. Site 6
Organic concentrations (mg L -1) at Site 6
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
0.0000 0.0005 0.0010 0.0015 0.0020 0.0025 0.0030
Site 1 organic concentrations (mg L-1)

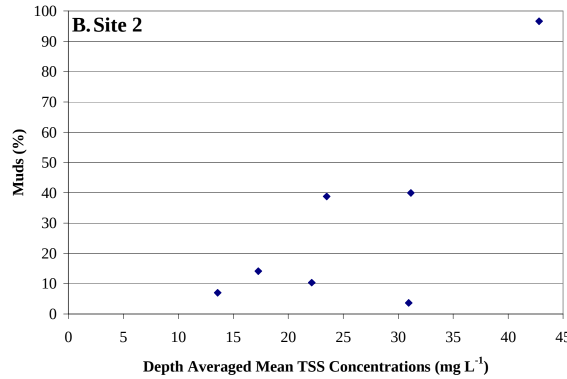

D. Site 7
Organic concentrations (mg L -1) at Site 7
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
0.0000 0.0005 0.0010 0.0015 0.0020 0.0025 0.0030
Site 1 organic concentrations (mg L-1)

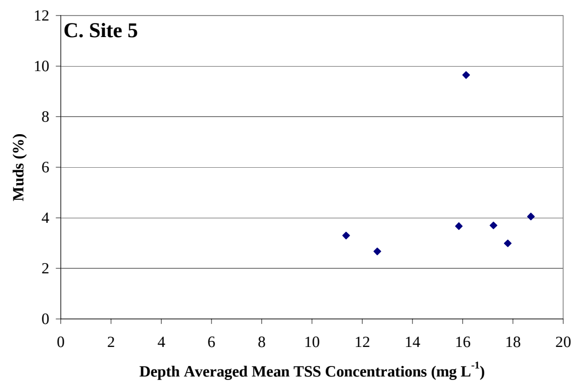

E. Site 8
Organic concentrations (mg L -1) at Site 8
0.0018
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
0.0000 0.0005 0.0010 0.0015 0.0020 0.0025 0.0030
Site 1 organic concentrations (mg L-1)

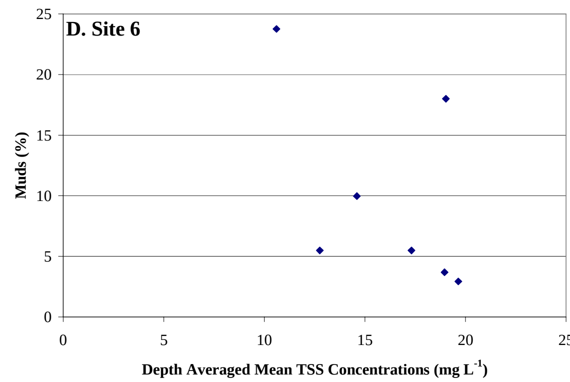

F. Site 9
Organic concentrations (mgL -1) at Site 9
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
0.0000 0.0005 0.0010 0.0015 0.0020 0.0025 0.0030
Site 1 organic concentrations (mg L-1)

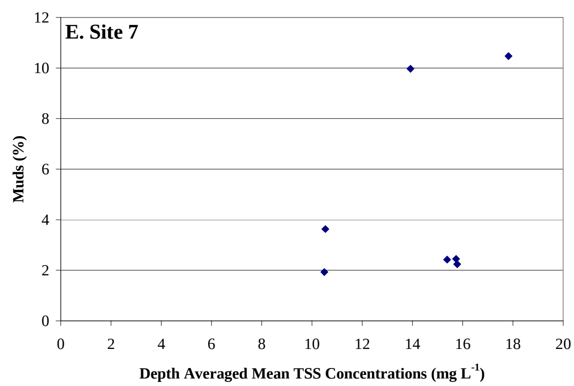
Appendix B. Scatter plots associated with Table 2

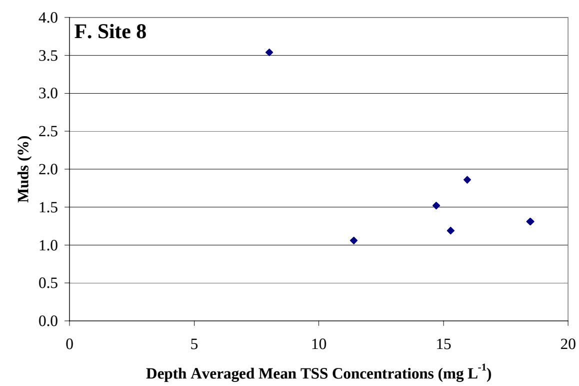


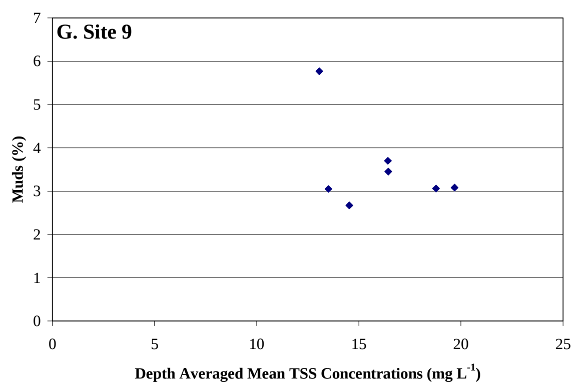


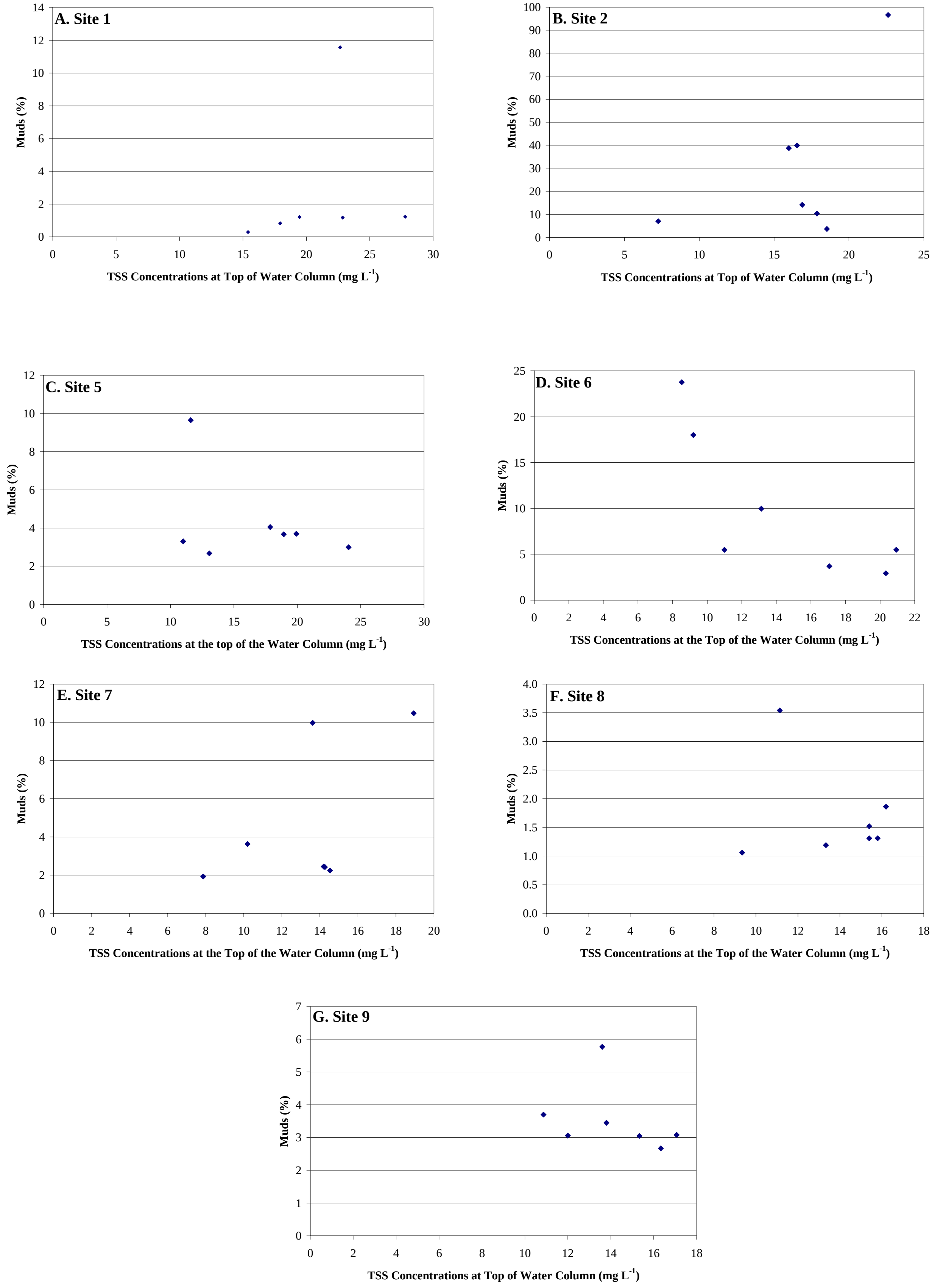


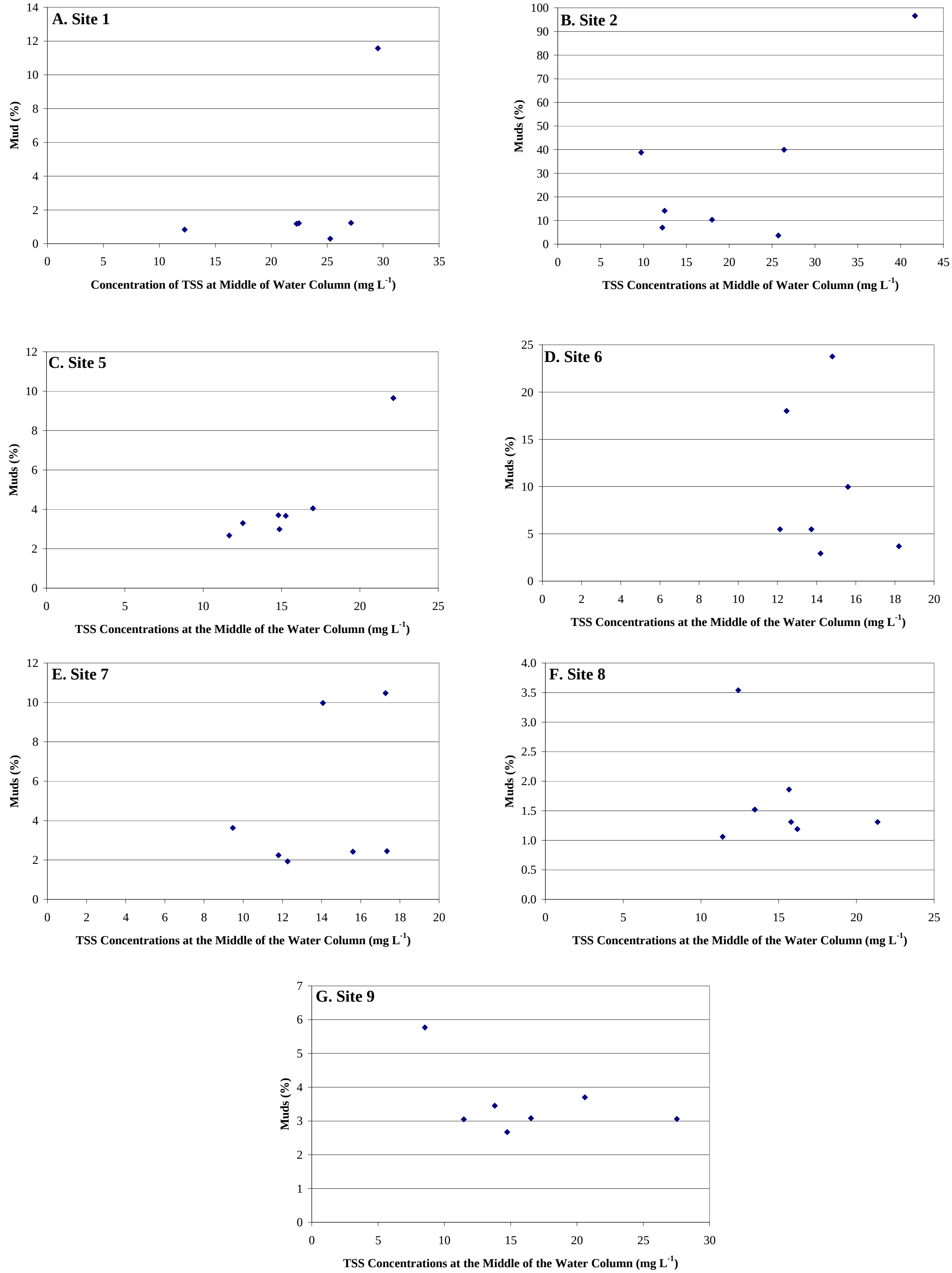


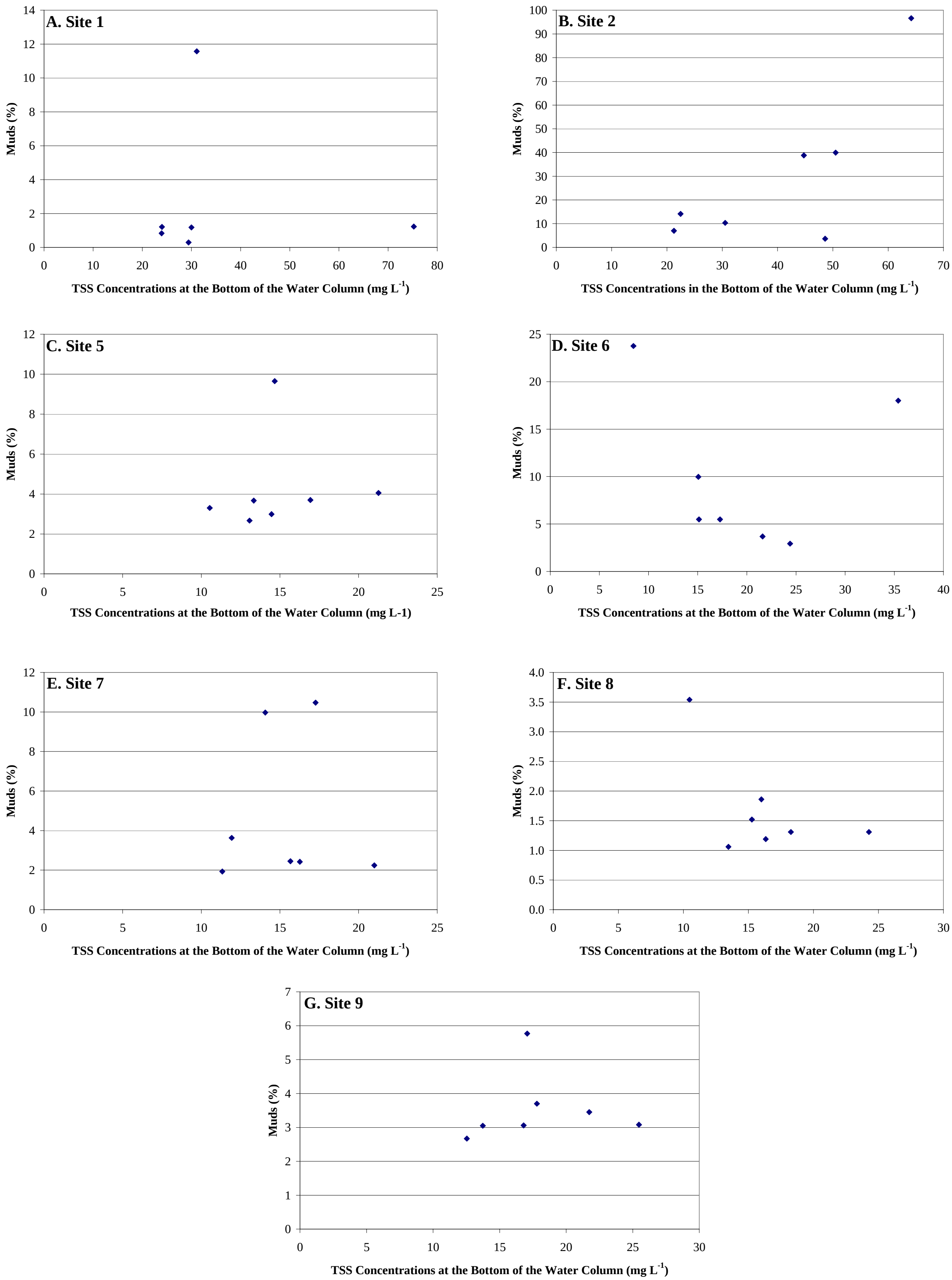


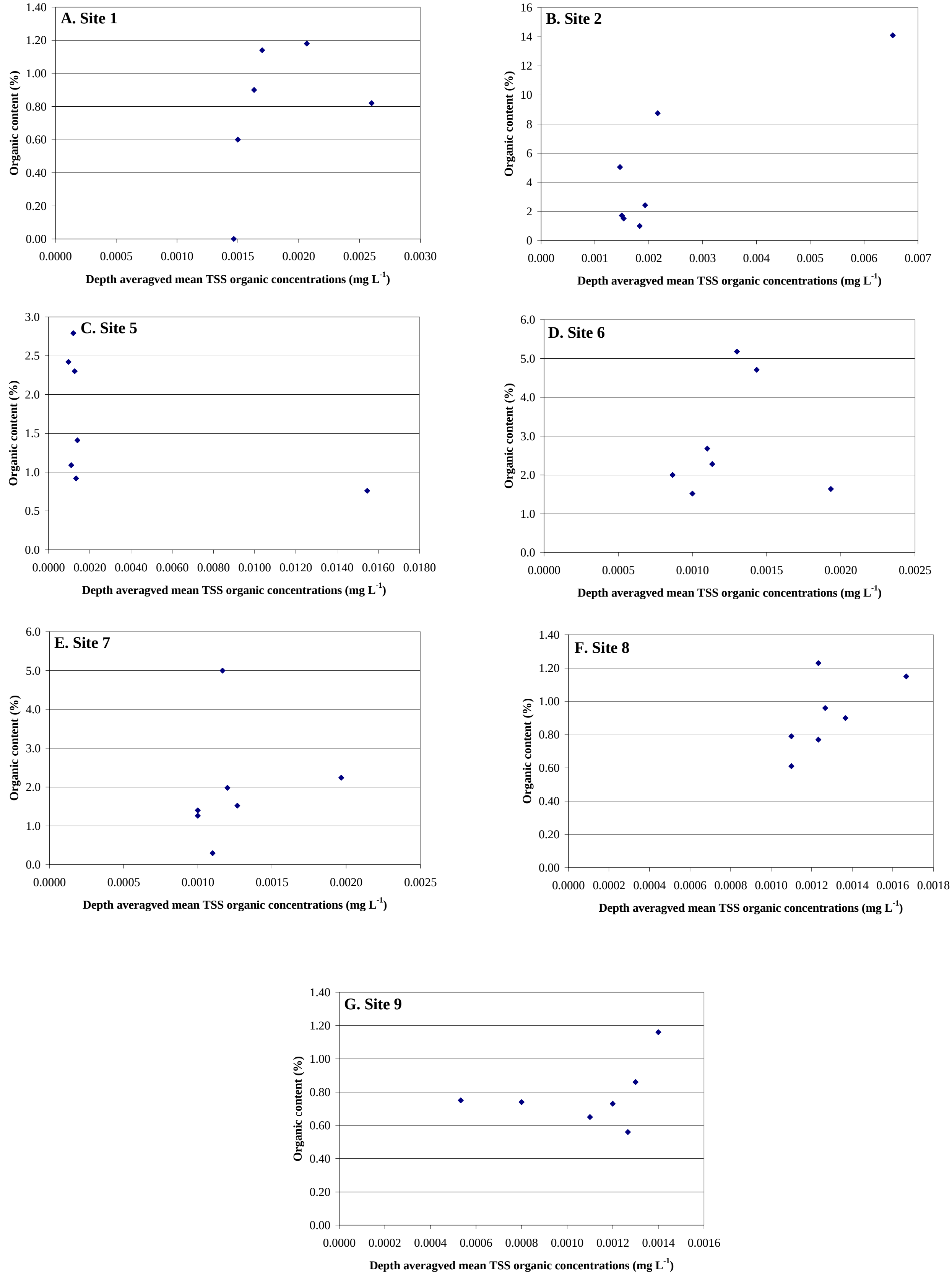




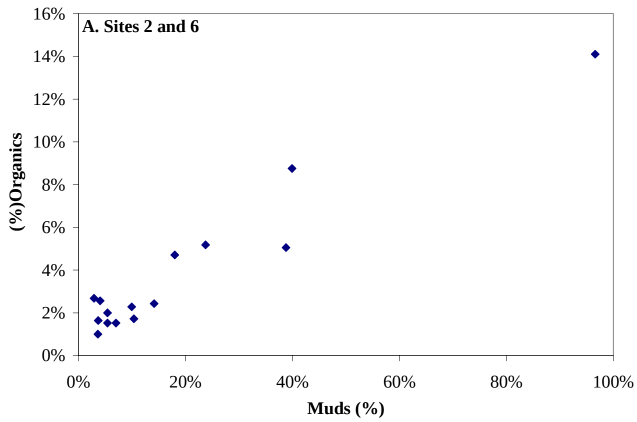

A. Site 1
Muds (%)
TSS Concentrations at Top of Water Column (mg L-1)
B. Site 2
Muds (%)
TSS Concentrations at Top of Water Column (mg L-1)
C. Site 5
Muds (%)
TSS Concentrations at the top of the Water Column (mg L-1)
D. Site 6
Muds (%)
TSS Concentrations at the Top of the Water Column (mg L-1)
E. Site 7
Muds (%)
TSS Concentrations at the Top of the Water Column (mg L-1)
F. Site 8
Muds (%)
TSS Concentrations at the Top of the Water Column (mg L-1)
G. Site 9
Muds (%)
TSS Concentrations at Top of Water Column (mg L-1)

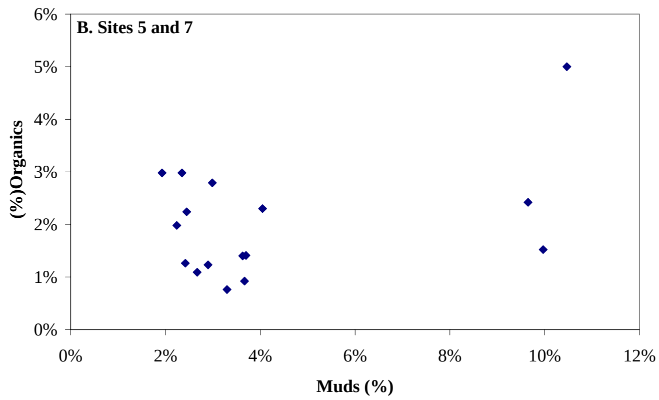

A. Site 1
Mud (%)
Concentration of TSS at Middle of Water Column (mg L-1)
B. Site 2
Muds (%)
TSS Concentrations at Middle of Water Column (mg L-1)
C. Site 5
Muds (%)
TSS Concentrations at the Middle of the Water Column (mg L-1)
D. Site 6
Muds (%)
TSS Concentrations at the Middle of the Water Column (mg L-1)
E. Site 7
Muds (%)
TSS Concentrations at the Middle of the Water Column (mg L-1)
F. Site 8
Muds (%)
TSS Concentrations at the Middle of the Water Column (mg L-1)
G. Site 9
Muds (%)
TSS Concentrations at the Middle of the Water Column (mg L-1)

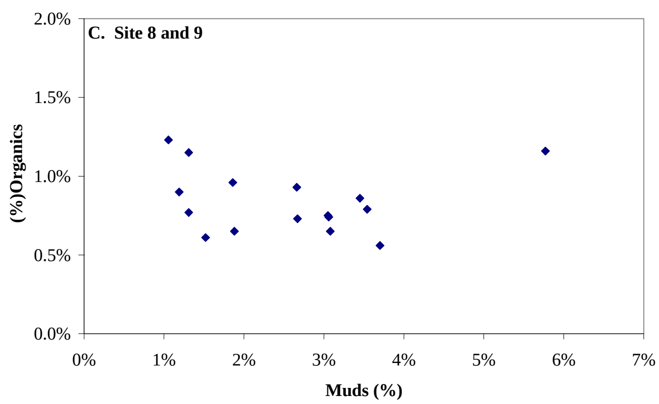

A. Site 1
Muds (%)
TSS Concentrations at the Bottom of the Water Column (mg L-1)
B. Site 2
Muds (%)
TSS Concentrations in the Bottom of the Water Column (mg L-1)
C. Site 5
Muds (%)
TSS Concentrations at the Bottom of the Water Column (mg L-1)
D. Site 6
Muds (%)
TSS Concentrations at the Bottom of the Water Column (mg L-1)
E. Site 7
Muds (%)
TSS Concentrations at the Bottom of the Water Column (mg L-1)
F. Site 8
Muds (%)
TSS Concentrations at the Bottom of the Water Column (mg L-1)
G. Site 9
Muds (%)
TSS Concentrations at the Bottom of the Water Column (mg L-1)

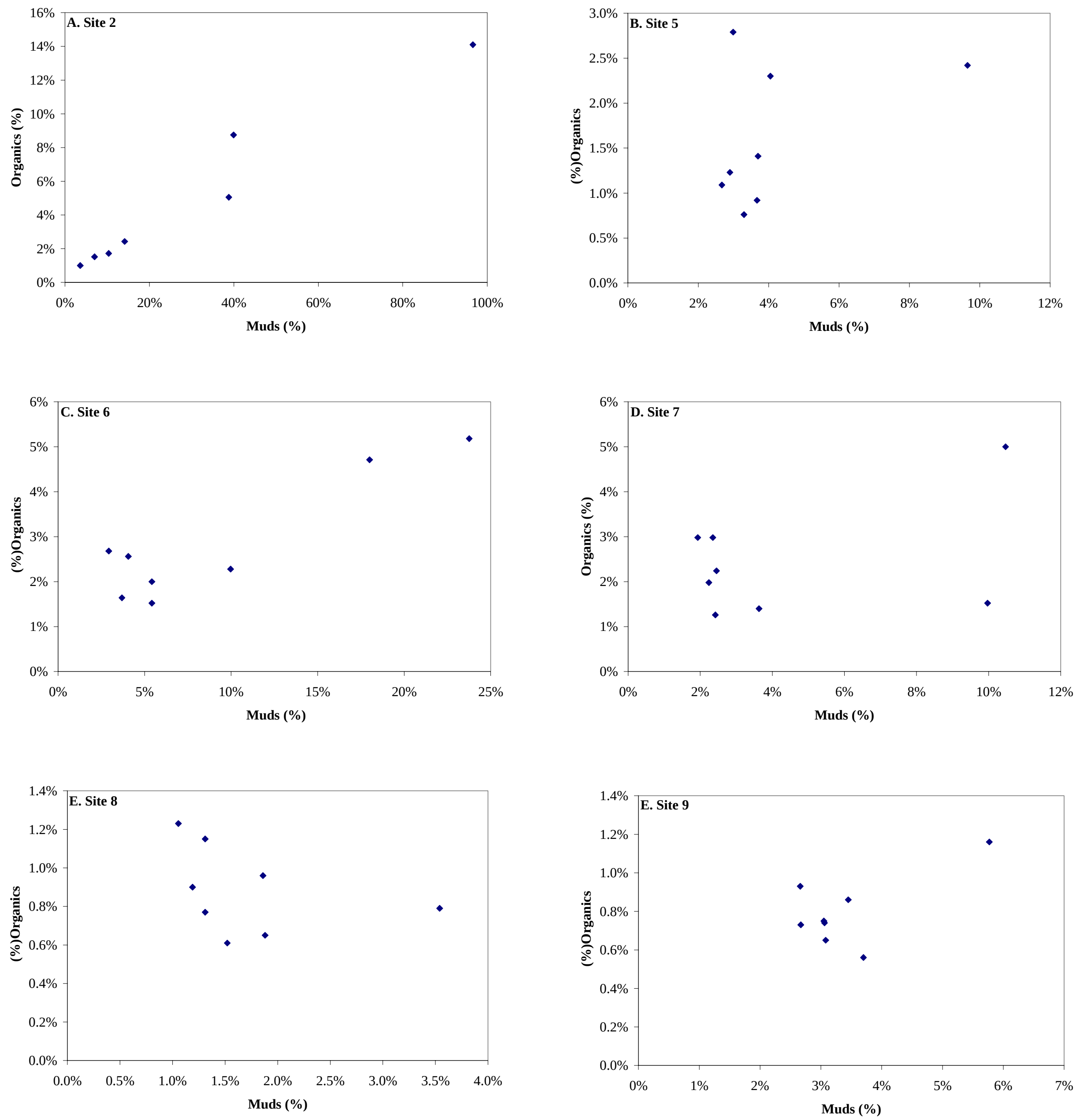

A. Site 1
B. Site 2
C. Site 5
D. Site 6
E. Site 7
F. Site 8
G. Site 9
Organic content (%)
Depth averagved mean TSS organic concentrations (mg L-1)

Appendix C. Scatter plots associated with table 3.








A. Site 2
Organics (%)
Muds (%)
B. Site 5
(%)Organics
Muds (%)
C. Site 6
(%)Organics
Muds (%)
D. Site 7
Organics (%)
Muds (%)
E. Site 8
(%)Organics
Muds (%)
E. Site 9
(%)Organics
Muds (%)